Chapter 2
U.S. and International Research and Development: Funds and Alliances

Contents

Highlights

National Trends in R&D Expenditures

♦ **Total annual research and development (R&D) expenditures in the United States were $227 billion in 1998 by current estimates.** This level of R&D expenditure represents a 6.5 percent increase, after adjusting for inflation, over the $211 billion spent in 1997. In turn, the 1997 estimate represents a 5.5 percent increase over the 1996 level after adjusting for inflation.

♦ **The entire economy of the United States, as measured by gross domestic product (GDP), was estimated to reach $8,509 billion in 1998.** Adjusted for inflation, GDP increased by 3.9 percent per year in 1997 and 1998. Such growth in GDP is exceptionally high, yet it is slower than the growth of R&D. R&D has generally been outpacing the overall growth of the economy since 1994. As a result, R&D as a proportion of GDP has been on the rise as well—from 2.43 percent in 1994 to 2.67 percent in 1998.

♦ **Despite this recent increase, the R&D share of GDP (2.67 percent in 1998) is still below levels reached in the early 1990s** (e.g., 2.72 percent in 1991). Since 1957, the highest R&D/GDP ratio was 2.88 percent in 1964; the low was 2.13 percent in 1978.

♦ **Since 1980, industry has provided the largest share of financial support for R&D. Industry's share of funding for R&D was projected to reach $150 billion in 1998, or 66 percent of the total.**

♦ **Industrial R&D performance—predominately "development"—grew by only 0.7 percent per year in inflation-adjusted ("real") terms from 1985 to 1994.** From 1994 to 1998, that growth rate increased to 7.6 percent annually in real terms.

♦ **The most striking change in industrial R&D performance during the past two decades may be the nonmanufacturing sector's increased prominence.** Prior to 1983, nonmanufacturing industries accounted for less than 5 percent of the industry R&D total. By 1993, this percentage had risen to an all-time high of 26 percent. It has fallen only slightly since then and has remained above 22 percent.

♦ **Federal R&D support in 1998 reached $67 billion, as reported by performers doing the work.** The Federal Government once was the main provider of the Nation's R&D funds—accounting for as much as 67 percent in 1964. Its share of support first fell below 50 percent in 1979, and it remained between 45 and 47 percent from 1980 to 1988. Since 1988 it has fallen steadily to 29.5 percent in 1998—the lowest ever recorded in the National Science Foundation's (NSF) data series (which began in 1953).

♦ **The provision of Federal R&D obligations is concentrated from several agencies.** Six Federal agencies had R&D obligations of more than $1 billion in FY 1998, out of the total Federal R&D obligations of $72.1 billion. These six agencies are, in descending order of R&D obligations, the Department of Defense (DOD) (with a 48.3 percent share of the total), the Department of Health and Human Services (HHS) (19 percent), the National Aeronautics and Space Administration (NASA) (13.7 percent), the Department of Energy (DOE) (8.1 percent), NSF (3.3 percent), and the Department of Agriculture (USDA) (2.0 percent).

♦ **In contrast to total R&D obligations, only three agencies had intramural R&D expenditures that exceeded $1 billion in 1998, including costs associated with planning and administering extramural R&D programs:** DOD, HHS (which includes the National Institutes of Health), and NASA. These three agencies together accounted for 81 percent of all Federal R&D obligations for 1998 and 77 percent of Federal intramural R&D.

♦ **State governments also provide funding for R&D activities.** In 1995 (the most recent year for which these data are available), almost 25 percent of the $244 million state-funded, state-performed R&D was health related. Between 1965 and 1995, total state R&D spending increased at an inflation-adjusted average annual rate of 3.3 percent, compared with nationwide R&D spending growth of 2.5 percent per year over the same period.

♦ **Between 1953 and 1969, R&D expenditures grew at a real annual rate of 8.2 percent.** Starting in 1969 and for nearly a decade thereafter, however, R&D growth failed to keep up with either inflation or general increases in economic output. In fact, between 1969 and 1975, real R&D expenditures declined by 1 percent per year as business and government tended to deemphasize research programs. Between 1975 and 1985, R&D expenditures picked up again, averaging 5.6 percent real growth per year. That rate then slowed to 1.1 percent in 1985–94. In 1994–98, R&D expenditures rose sharply again, averaging 5.8 percent real growth per year. Almost all of the recent growth in national R&D expenditures is the result of a resurgence of industrial R&D.

♦ **R&D is substantially concentrated in a small number of states.** In 1997, California had the highest level of R&D expenditures—$41.7 billion, representing approximately one-fifth of the $199.1 billion U.S. total that could be attributed to individual states. The six states with the highest levels of R&D expenditures—California, Michigan, New York, New Jersey, Massachusetts, and Texas—accounted for approximately one-half of the entire national effort. The top 10 states—adding, in descending order, Pennsylvania, Illinois, Washington, and Maryland—accounted for approximately two-thirds of the national effort.

- **The United States spent $37.9 billion on the performance of basic research in 1998, $51.2 billion on applied research, and $138.1 billion on development, by current estimates.** These totals are the result of continuous increases over several years. They reflect a 4.7 percent annual increase, in real terms, for basic research; 3.9 percent for applied research; and 3.4 percent for development since 1980. As a share of all 1998 R&D performance expenditures, basic research represented 16.7 percent, applied research 22.5 percent, and development 60.8 percent. These shares have not changed very much over time.

- **R&D in the broad area of the life sciences is characterized by strong and fairly continuous real growth.** Federal obligations for research in the life sciences rose from $8 billion in 1985 (in constant 1992 dollars) to $11 billion in 1996. Company-funded R&D in drugs and medicines grew dramatically in real terms, from $4 billion in 1985 to $10 billion in 1997. Likewise, academic R&D (not Federally funded) in the life sciences and bioengineering/biomedical engineering grew continuously, from $3 billion in 1985 (in constant 1992 dollars) to $5 billion in 1996.

- **Growth in collaborative research is an important trend in R&D activities as a means of synergizing R&D investments.** By the end of 1998, 741 research joint ventures (RJVs) associated with NCRA and the National Cooperative Research and Production Act had been registered. By 1998, however, the number of new RJV filings had fallen sharply to 31 per year, after having reached a peak of 115 in 1996.

- **Cooperative research and development agreements (CRADAs) between Federal agencies and other sectors grew in number geometrically, from 34 in 1987 to 3,688 in 1996 (averaging 68 percent growth per year).** Between 1996 and 1997, however, the number of active CRADAs declined to 3,239.

International Comparisons of National R&D Trends

- **The United States accounts for roughly 43 percent of the industrial world's R&D expenditure total.** U.S. R&D investments continue to outdistance, by more than 2 to 1, R&D investments made by Japan, the second largest performer. Not only did the United States spend more money on R&D activities in 1997 than did any other country, it also spent as much by itself as the other "group of seven" (G-7) countries—Canada, France, Germany, Italy, Japan, and the United Kingdom—combined. In terms of nondefense R&D spending, however, combined expenditures in those six countries exceeded nondefense R&D spending in the United States by 17 percent in 1996.

- **Relative to shares reported in other G-7 countries, U.S basic research spending (17 percent of its R&D total) is less than the shares reported for Germany, France, and Italy (each at 21–22 percent) but higher than the basic research share in Japan (12 percent of its R&D total).** Basic research accounts for 18 percent of Russia's R&D total.

- **There was a worldwide slowing in R&D spending in large and small countries in the early 1990s.** In fact, inflation-adjusted R&D spending fell for three consecutive years (1992, 1993, and 1994) in the United States, Japan, Germany, and Italy. R&D spending has since recovered in these countries but has remained stagnant in France and the United Kingdom. Most of the recent R&D growth results from rebounding industrial nondefense spending.

- **The most notable trend among G-7 and other Organisation for Economic Co-operation and Development (OECD) countries has been the relative decline in government R&D funding.** In 1997, roughly one-third of all OECD R&D funds derived from government sources—down considerably from the 45 percent share reported 16 years earlier. Much of this change reflects a decline in industrial reliance on government funds for R&D performance. In 1981, government provided 23 percent of the funds used by industry in the conduct of R&D within OECD countries. By 1997, government's share of the industry R&D total had fallen by more than one-half, to 10 percent of the total.

- **Even with the recovery in R&D spending in many G-7 countries, their R&D/GDP ratios generally are no higher now than they were at the start of the 1990s.** The U.S. R&D/GDP ratio inched back up to 2.7 percent in 1998 from its 16-year low of 2.4 percent in 1994. The United States ranked sixth among OECD countries in terms of reported R&D/GDP ratios for 1995–97. Sweden leads all countries with a R&D/GDP ratio of 3.9 percent, followed by Japan and South Korea (2.9 percent), Finland (2.8 percent), and Switzerland (2.7 percent).

- **R&D spending in the Russian Federation remains considerably below levels in place prior to the introduction of a market economy.** R&D downsizing and restructuring of obsolete, state-owned (generally military-oriented) enterprises were undertaken to establish viable commercial and scientific R&D infrastructures. In 1997, inflation-adjusted R&D spending was 74 percent below the level reported for 1990, and the number of scientists and engineers employed in research was less than half the number estimated to be employed in 1990.

- **Worldwide changes in the R&D landscape are presenting governments with a variety of new challenges and**

opportunities. Defense R&D has been substantially reduced not only in the United States but also in the United Kingdom and France, where the national defense share of the government R&D total declined from 44 percent to 38 percent and from 40 percent to 28 percent, respectively, during the 1990–97 period.

- ♦ **Among nondefense functions, U.S. government R&D spending for health is far greater than for any other activity.** Health accounts for about 19 percent of government R&D, making it second only to defense R&D activities. In the United Kingdom, 15 percent of the government's R&D support is health related. Several additional nondefense functions are emphasized to different degrees among other G-7 countries. Relatively large shares of government R&D support are devoted to energy in Japan; to space in France and the United States; and to industrial development in Canada, Germany, and Italy.

- ♦ **Many countries have put fiscal incentives into place to increase the overall level of R&D spending and to stimulate industrial innovation.** Almost all industrialized countries (including the United States) allow industry R&D expenditures to be 100 percent expensed (written off as costs in expense statements) in the year they are incurred, and about half of these countries (including the United States) provide some type of additional R&D tax credit or incentive. In fiscal year 1998, U.S. industry received an estimated $3.2 billion through tax credits on incremental research and experimentation expenditures. About 15 states in the United States offer additional R&D tax credits. Most countries (including the United States) provide preferential R&D programs for small businesses.

- ♦ **International partnerships have become a pillar in the global R&D landscape.** In many countries, the rapid rise in international cooperation has spawned activities that now account for more than 10 percent of government R&D expenditures. According to a 1999 study, seven agencies of the U.S. government participated in 575 international science and technology agreements in FY 1997 with 57 countries, 8 international organizations, and 10 groups of organizations or countries.

- ♦ **Industrial firms increasingly have used global research partnerships to strengthen core competencies and expand into technology fields critical for maintaining market share.** Since 1990, companies worldwide have entered into more than 5,100 known multifirm R&D alliances involving strategic high-technology activities. About one-third of these alliances were between U.S. firms and European or Japanese firms. Alliances were created most often to develop and share information technologies.

- ♦ **Worldwide, an increasing share of industrial R&D performance is financed by foreign (generally industry) sources.** U.S. companies make substantial R&D investments overseas ($13.1 billion in 1997). From 1985 to 1996, U.S. firms' investment in overseas R&D increased almost three times faster than company-funded R&D performed domestically (9.7 percent versus 3.4 percent average annual constant-dollar growth). Equivalent to about 6 percent of industry's total (domestic plus overseas) R&D funding in 1985, overseas R&D represented 10.4 percent of U.S. industry's R&D funding in 1996. In 1997, strong growth in companies' domestic financing for research (up 10 percent) coupled with a 7 percent decline in industry's overseas R&D spending reduced the overseas share to 8.9 percent of companies' R&D total.

- ♦ **More than two-thirds of U.S.-funded R&D abroad was performed in Europe—primarily in Germany, the United Kingdom, and France.** The current European share of U.S. industry's offshore R&D activity, however, is less than the 75 percent share reported for 1982. Overall, U.S. R&D investments abroad have generally shifted from the larger European countries and Canada toward Japan, several of the smaller European countries (notably Sweden and the Netherlands), Australia, and Brazil. Pharmaceutical companies accounted for the largest industry share (18 percent of U.S. 1997 overseas R&D), which was equivalent to 21 percent of their domestically financed R&D. Much of this pharmaceutical R&D took place in the United Kingdom.

- ♦ **U.S. firms are known to have established at least 186 R&D facilities in other countries by 1997.** Japan leads all countries as the site of overseas U.S. R&D facilities (43), followed by the United Kingdom, Canada, France, and Germany. Most U.S.-owned foreign facilities support the automotive (32 facilities), drugs and biotechnology (28), computers (25), and chemicals and rubber (23) industries.

- ♦ **Substantial R&D investments are made by foreign firms in the United States.** From 1987 to 1996, inflation-adjusted R&D growth from majority-owned U.S. affiliates of foreign firms averaged 10.9 percent per year. This growth contrasts favorably with the 3.9 percent average annual rate of increase in U.S. firms' domestic R&D funding. R&D expenditures in the United States by foreign companies are now roughly equivalent to U.S. companies' R&D investment abroad. Affiliates of firms headquartered in Germany, Switzerland, the United Kingdom, France, Japan, and Canada collectively account for 81 percent of this foreign funding.

- ♦ **Foreign-funded R&D in the United States in 1996 was concentrated in drugs and medicines (mostly from Swiss, German, and British firms), industrial chemicals (funded predominantly by German and Dutch firms), and electrical equipment (one-third of which came from French affiliates).** More than 700 R&D facilities run by 375 foreign-owned companies from 24 different countries are located in the United States.

Introduction

Chapter Overview

The U.S. economy approaches the end of the 20th century with unprecedented real growth, miniscule inflation, low unemployment, and strong consumer and investor confidence. Economists have dubbed it the "Cinderella economy." The reasons for this success are many and varied. However, it can be argued that technological change has been behind the economic boom of the late 1990s.

Technological change has three general effects on the economy. First, it reduces the costs of producing goods and providing services. That is, technological change allows for the consumption of greater amounts of goods and services, without the use of greater amounts of human labor, physical capital, or natural resources. Second, technological change is responsible for the creation of new and improved goods and services. Although the relative value of any new product is subjectively determined by each individual, the spending patterns of consumers overall often reveal the preferability of these new products over their predecessors. Ironically, the third factor—what technological change has not yet done, but is expected to do—may have made the greatest contribution to the recent economic boom. Technological change is expected to continue to transform many aspects of economic production, distribution, and consumption. Such changes include, for example, further development of Internet commerce (e.g., banking and retail operations), additional advances in biotechnology (e.g., "designer" drugs), greater automation in production (e.g., advanced robotic systems), new forms of household entertainment (e.g., digital video disc entertainment systems), and new ways of conducting scientific research itself (e.g., the creation of virtual laboratories). Investors and public planners have continued to devote new resources to preparing for these changes, thereby stimulating economic investment and expansion. Thus, much of the current investment-led economic growth is only a prelude to future advances. In this sense, our present is being influenced largely by our future—a future that will owe much of its character to technological change.

Of course, innovation—and the technological change that results from it—does not just happen. It has to be paid for—through expenditures on research and development (R&D). How R&D funds are spent helps determine how scientific knowledge will accumulate and how technological change will be manifested. Thus, R&D decisionmaking—how much different organizations spend and on what areas of science or engineering—is critical to the future of the U.S. economy and national well-being. This factor explains why the United States and many other nations collect extensive R&D expenditures data and disseminate the information worldwide for study by analysts in a wide variety of fields.

In addition to indicating the directions of technological change, R&D expenditure data also measure the level of economic purchasing power that has been devoted to R&D projects as opposed to other economic activities. Industrial (private sector) funding of R&D, for example—which represents most of R&D expenditure in the United States—may be interpreted as an economic metric of how important R&D is to U.S. companies, which could have easily devoted those same funds to any number of other business activities. Likewise, government support for R&D reflects government and society's commitment to scientific and engineering advancement, which is an objective that must compete for dollars against other functions served by discretionary government spending. The same basic notion holds for other sectors that fund R&D, such as colleges and universities and other nonprofit organizations.

Total R&D expenditures therefore reveal the *perceived* economic importance of R&D *relative* to all other economic activities. Because institutions invest in R&D without knowing the final outcome (if they did, it would not be R&D), the amount they devote is based on their perception, rather than their absolute knowledge, of R&D's value. Such information about R&D's perceived relative value is also extremely useful for economic decisionmaking. For example, increased R&D in a particular field of study may reflect an increase in demand for scientists and engineers to study and work in that field. An increase in R&D in a particular industrial sector could be among the first signs that the sector is about to expand with new lines of products or services. Of course, R&D data alone are not enough to accurately analyze the future growth of a field of study or an industrial sector, but they may well be an important input into such analysis. This chapter therefore presents information that will provide a broad understanding of the nature of R&D expenditures and the implications of these data for science and technology policy.

Chapter Organization

This chapter has two major parts, both of which examine trends in R&D expenditures. The first part looks into R&D performed in the U.S. alone; the second compares R&D trends across nations. The first part contains sections on economic measures of R&D; trends in financial support for R&D; trends in R&D performance; industrial R&D performance; R&D performance by geographic location, character of work, and field of science; and intersector and intrasector R&D partnerships and alliances. The second part contains sections on total and nondefense R&D spending; ratios of R&D to gross domestic product (GDP) among different nations; international R&D funding by performer and source; the character of R&D efforts (or R&D efforts separated into basic research, applied research, and development components); international comparisons of government R&D priorities; comparisons of government R&D tax policies; the growth in public- and private-sector international R&D agreements and alliances; the United States' international R&D investment balance; and patterns in overseas R&D and foreign R&D performed in the United States, in terms of both expenditures and facility placement.

Economic Measures of R&D

Latest Developments in U.S. National R&D

The United States is spending more money on R&D than ever before, even when the amounts are adjusted for inflation. In 1998 (the most recent year for which R&D expenditure data are available at this writing), total R&D expenditures in the United States reached $227.2 billion.[1] Moreover, the rate at which R&D has been increasing in recent years has been impressive. The $227.2 billion total for 1998 reflects a nominal growth rate (without accounting for inflation) of 7.5 percent over the 1997 level of $211.3 billion, or a real growth rate (after adjusting for inflation) of 6.5 percent.[2] Similar growth occurred in 1997: The 1997 level of R&D reflects a 7.5 percent nominal growth over the $196.5 billion spent in 1996, or 5.5 percent real growth.

By comparison, the U.S. GDP,[3] the main measure of the nation's total economic activity, grew in real terms by 3.9 percent per year in 1997 and 1998. Such growth in the GDP is exceptionally high, yet it is slower than the growth of R&D. R&D has generally been outpacing the overall growth of the economy since 1994. As a result, R&D as a proportion of GDP has been on the rise as well—from 2.43 percent in 1994 to 2.67 percent in 1998.

Organizations that conduct R&D often receive outside funding; likewise, organizations that fund R&D often do not perform as much R&D as the amount of money they devote to it. Therefore, any discussion of the nation's R&D must always be careful to distinguish between where the money comes from originally and where the R&D is actually performed. That is, R&D expenditures can be categorized, respectively, by source of funds or by performer.

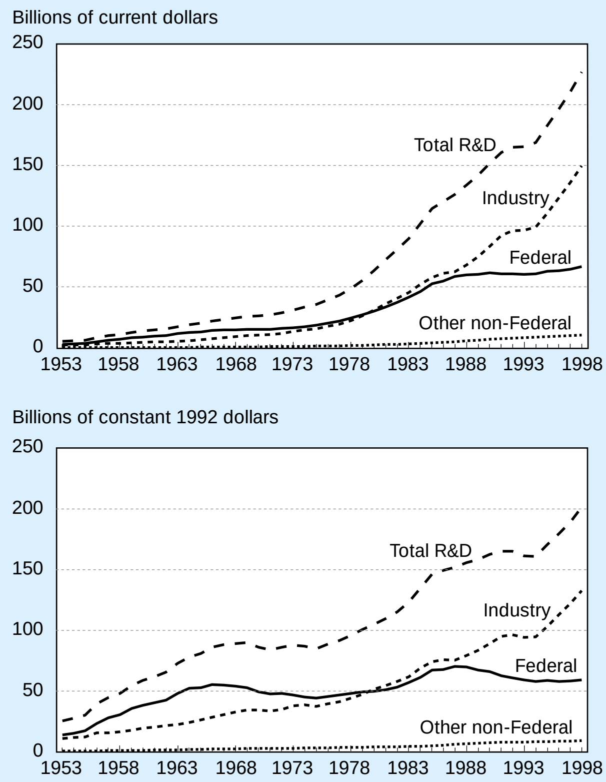
By source of funds, most of the nation's R&D is paid for by private industry, which provided 65.9 percent ($149.7 billion) of total R&D funding in 1998. Nearly all of these funds (98 percent) were used by private industry itself in the performance of its own R&D, and most of these funds (70 percent) were for the development of products and services rather than for research. In 1998, the Federal Government provided the next largest share of R&D funding—29.5 percent ($66.9 billion dollars)—and the other sectors of the economy (state governments, universities and colleges, and nonprofit institutions) contributed the remaining 4.7 percent ($10.6 billion). (See figures 2-1, 2-2, and 2-3 and text table 2-1.)

By performer, industry in 1998 accounted for an even larger share of the total—74.4 percent; universities and colleges accounted for 11.6 percent, and the Federal Government accounted for 7.6 percent. Federally Funded Research and Development Centers (FFRDCs)—which are administered by various industrial, academic, and nonprofit institutions—accounted for an additional 3.8 percent, and other nonprofit organizations accounted for 2.6 percent. (See figures 2-2 and 2-3.)[4]

R&D Growth Trends

Between 1953 and 1969 R&D expenditures grew at a real annual rate of 8.2 percent.[5] Starting in 1969, however, and for nearly a decade thereafter, R&D growth failed to keep up with either inflation or general increases in economic output. In fact, between 1969 and 1975, real R&D expenditures declined by 1 percent per year as business and government tended to deemphasize research programs. (See figure 2-1.)

Figure 2-1.
National R&D funding, by source: 1953–1998



See appendix tables 2-5 and 2-6.

Science & Engineering Indicators – 2000

[1]Projections for 1998 and preliminary tabulations for 1997 were based in part on time-series modeling techniques. Except for discussions of the Federal budget authority, which refer to fiscal years, other references to years in this chapter refer to calendar years, not fiscal years (even in discussions of academic and Federal intramural performance). Other chapters in this report and other NSF reports on academic or Federal expenditures alone, however, often refer to fiscal years because those institutions operate on a fiscal year basis. Calendar years are used in this chapter and in the NSF reports *National Patterns of R&D Resources* and *Research and Development in Industry*, however, for consistency with industry data, which represent three-fourths of U.S. R&D expenditure, and for consistency with the vast majority of all other national economic statistics provided by Federal statistical agencies.

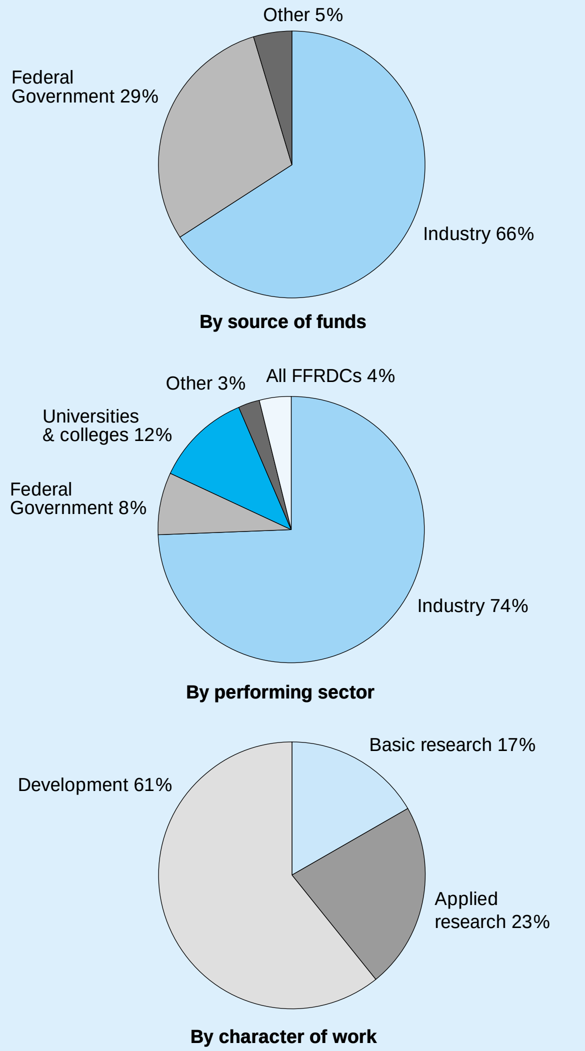
[2]For a discussion of how dollar amounts are adjusted for inflation, see "Appendix A: Controlling for Inflation and Foreign Currency," in NSF (1999c).

[3]For historical data on the GDP, see appendix table 2-1.

[4]In some of the statistics provided below, FFRDCs are included as part of the sector that administers them. In particular, statistics on the industrial sector often include industry-administered FFRDCs as part of that sector because some of these statistics from the NSF Industry R&D Survey cannot be separated with regard to the FFRDC component. Whenever a sector is mentioned in this chapter, the wording used will specify whether FFRDCs are included.

[5]For additional background on U.S. R&D in the 1950s, see chapter 1.

Figure 2-2.
National R&D expenditures: 1998



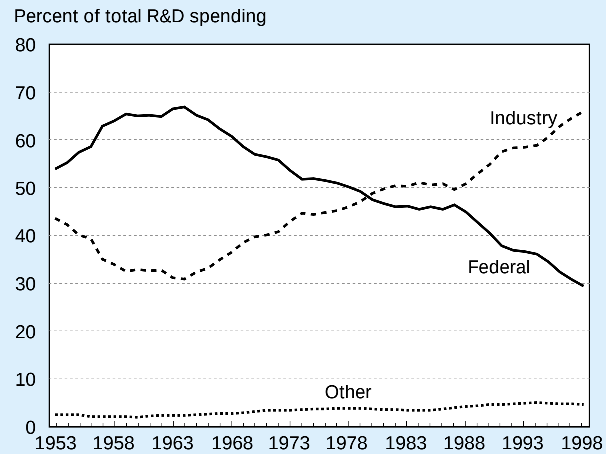
FFRDCs = Federally Funded Research and Development Centers

NOTE: Data labels rounded to nearest whole number.

See appendix tables 2-3, 2-5, 2-7, 2-11, and 2-15.

Science & Engineering Indicators – 2000

Figure 2-3.
National R&D expenditures, by source of funds



See appendix table 2-5. *Science & Engineering Indicators – 2000*

Federal funding in particular fell 19 percent in real terms during this period; this decrease was felt in defense- and nondefense-related programs (as discussed in greater detail below).

The situation turned around in the mid-1970s. Following an economic recovery from the 1974 oil embargo and the 1975 recession, R&D expenditures increased in real terms by approximately 72 percent from 1975 to 1985 (5.6 percent per year), compared with a 37 percent rise in real GDP over the same period. During the first half of this period (1975–80), there was considerable growth in Federal R&D funding for nondefense activities. Although defense-related R&D expenditures rose as well, much of the Federal R&D gain was attributable to energy-related R&D (particularly nuclear energy development) and to greater support for health-related R&D. Non-Federal R&D increases were concentrated in industry and resulted largely from greater emphasis on energy conservation and improved use of fossil fuels. Consequently, energy concerns fostered increases in R&D funding by Federal and non-Federal sources. In particular, support for energy R&D rose more than 150 percent in real terms between 1974 and 1979 and accounted for approximately one-half of the national increase in real R&D spending.

Overall, the 1975–80 R&D recovery witnessed an average growth rate of 4.4 percent per year. That annual rate remained between 4 and 5 percent through 1982, though the early 1980s saw a heavy shift toward defense-related activities. As a result of these increases in defense R&D, growth in real R&D expenditures accelerated to an average annual rate of 8.2 percent over 1982–85. Such rapid growth had not been seen since the post-Sputnik era of the early 1960s.

On average, R&D spending increased 6.8 percent per year in real terms in the first half of the 1980s. The situation then changed abruptly again. From 1985 to 1994, average annual R&D growth after inflation slowed to 1.1 percent, compared with a 2.4 percent annual real growth in GDP. Reductions in Federal and non-Federal funding of R&D as a proportion of GDP had contributed to this slowing. However, the decline in real Federal R&D funding was the primary factor in the slow growth of R&D in the early 1990s.[6]

This downward trend reversed again in 1994, as a result of substantial increases in industrial R&D.[7] R&D in the United

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[6] These findings are based on performer-reported R&D levels. In recent years, increasing differences have been detected in data on Federally financed R&D as reported by Federal funding agencies, on the one hand, and by performers of the work (Federal labs, industry, universities, and other nonprofit organizations), on the other hand. For a discussion of this divergence in R&D totals, see sidebar, "Accounting for Defense R&D: Gap Between Performer- and Source-Reported Expenditures."

[7] For a detailed discussion of this upturn, see Jankowski (1999).

Text table 2-1.
U.S. R&D expenditures, by performing sector, source of funds, and character of work: 1998
(Millions of U.S. dollars)

Character of work/ sources of funds	Performer: Federal Government	Industry[a]	Universities and colleges	U&C associated FFRDCs[b]	Other nonprofit institutions[a]	Total	Percent distribution by sources
TOTAL R&D							
Federal Government	17,189	24,589	15,558	5,517	4,077	66,930	29.5%
Industry	..	146,706	1,896	..	1,051	149,653	65.9%
Universities and colleges	..	..	7,049	..	..	7,049	3.1%
Other nonprofit institutions	..	..	1,840	..	1,702	3,541	1.6%
Total.	17,189	171,295	26,343	5,517	6,830	227,173	100.0%
Percent distribution, performers	7.6%	75.4%	11.6%	2.4%	3.0%	100.0%	
BASIC RESEARCH							
Federal Government	2,920	1,816	11,248	2,721	1,531	20,235	53.4%
Industry	..	9,625	1,205	..	483	11,313	29.9%
Universities and colleges	..	..	4,479	..	..	4,479	11.8%
Other nonprofit institutions	..	..	1,169	..	681	1,850	4.9%
Total.	2,920	11,441	18,100	2,721	2,695	37,877	100.0%
Percent distribution, performers	7.7%	30.2%	47.8%	7.2%	7.1%	100.0%	
APPLIED RESEARCH							
Federal Government	5,421	3,087	3,130	1,545	1,144	14,326	28.0%
Industry	..	32,701	567	..	357	33,625	65.6%
Universities and colleges	..	..	2,107	..	..	2,107	4.1%
Other nonprofit institutions	..	..	550	..	613	1,163	2.3%
Total.	5,421	35,788	6,354	1,545	2,114	51,221	100.0%
Percent distribution, performers	10.6%	69.9%	12.4%	3.0%	4.1%	100.0%	
DEVELOPMENT							
Federal Government	8,848	19,686	1,181	1,251	1,403	32,369	23.4%
Industry	..	104,380	124	..	210	104,715	75.8%
Universities and colleges	..	..	463	..	..	463	0.3%
Other nonprofit institutions	..	..	121	..	408	529	0.4%
Total.	8,848	124,066	1,888	1,251	2,021	138,075	100.0%
Percent distribution, performers	6.4%	89.9%	1.4%	0.9%	1.5%	100.0%	

FFRDC = Federally Funded Research and Development Center

NOTE: State and local government funds are included in industry funds reported to industry performers, and in university and college funds reported to university and college performers. Details may not add to totals because of rounding.

[a]Expenditures for FFRDCs administered by both industry and nonprofit institutions are included in the totals of their respective sectors. They are estimated to account for less than 2 percent and 12 percent, respectively, of the industry and nonprofit institutions performance totals. FFRDCs are organizations exclusively or substantially financed by the Federal Government to meet a particular requirement or to provide major facilities for research and training purposes.

[b]FFRDCs administered by individual universities and colleges and by university consortia.

See appendix tables 2-3 , 2-7, 2-11, and 2-15.

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States grew in real terms by 5.8 percent per year between 1994 and 1998, in spite of virtually no real growth (0.6 percent per year) in Federal R&D support. Over the same period, industrial support for R&D grew at a real annual rate of 8.9 percent. Much of this increase might be explained by the favorable economic conditions that generally existed during the period.

Trends in Financial Support for R&D

Federal Support by National Objective

Federal Funding Trends

In recent years the Federal Government has contributed smaller shares of the Nation's R&D funding. The Federal Government once was the main provider of the Nation's R&D funds—accounting for 54 percent in 1953 and as much as 67 percent in 1964. The Federal share of R&D funding first fell below 50 percent in 1979, and it remained between 45 and 47 percent from 1980 to 1988. Since then it has fallen steadily, to 29.5 percent in 1998—the lowest ever recorded in the National Science Foundation's (NSF) data series (which began in 1953).[8] This decline in the Federal share, however, should not be misinterpreted as a decline in the actual amount funded. Federal support in 1998 ($66.9 billion), for example, actually reflects a 2.1 percent increase in real terms over the 1997 level. Because industrial funding increased much faster (see above), however, Federal support as a proportion of the total has continued to decline.

Although the Federal share of total R&D expenditures continued to fall, Federal R&D funding, in absolute terms, actually expanded between 1980 and 1998 (from $30.0 billion to $66.9 billion)—which, after inflation, amounted to a small, real growth rate of 1.0 percent per year. This rate was not uniform across the period, however. From 1980 to 1985, Federal R&D funding grew an average of 6.2 percent in real terms annually. Nearly all of the rise in Federal R&D funding during the early 1980s resulted from large increases in defense spending—as evidenced by figures on the Federal budget authority. (See figure 2-4.) For example, defense activities of the Department of Defense (DOD) and the Department of Energy (DOE) accounted for roughly half of the total Federal R&D budget authorizations in 1980.[9] By 1986, such defense-related activities peaked at 69 percent of the Federal R&D budget authority.

Federal support slowed considerably beginning in 1986—reflecting the budgetary constraints imposed on all government programs, including those mandated by the Balanced Budget and Emergency Deficit Control Act of 1985 (also known as the Gramm-Rudman-Hollings Act) and subsequent legislation (notably the Budget Enforcement Act of 1990, which mandated that new spending increases be offset with specific spending cuts).

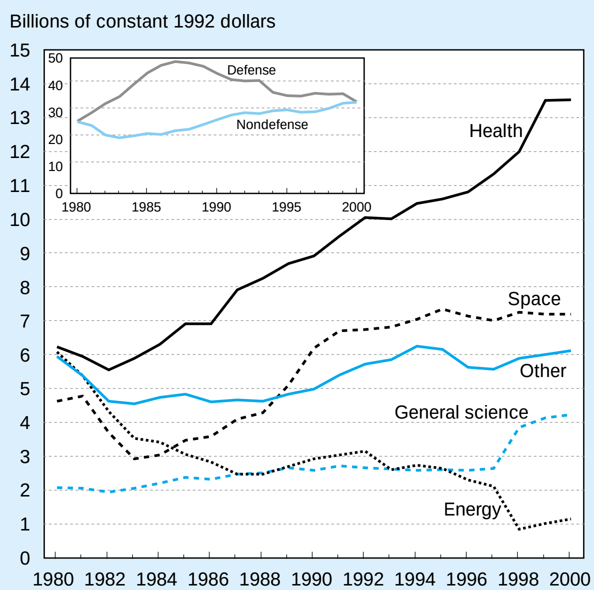
Federal Support by Budget Function

In 1980, the Federal budget authority for defense-related R&D was roughly equal to that for nondefense R&D. As a result of modifications in U.S. security measures in an evolving international arena, defense-related R&D expanded in the early and mid-1980s, coinciding with a decline in nondefense-R&D spending. This defense-related R&D expansion was followed by a period of defense-related R&D reductions in the late 1980s and the 1990s. Nondefense R&D, on the other hand, has been steadily increasing since 1983. For the year 2000, the budget authority for defense R&D and nondefense R&D are roughly equal again, but they are now 28 percent and 29 percent higher in real terms than their respective 1980 levels.

Since 1986, Federal budget authority for civilian-related R&D has grown faster than defense-related R&D. In particular, the budget allocation for health- and space-related R&D increased substantially between FY 1986 and FY 2000, with average real annual growth rates of 4.9 and 5.1 percent, respectively. (Most of the growth in the budget authority for space-related R&D occurred between FY 1986 and FY 1991.) (See figure 2-4.) The budget allocation for defense programs declined by an average real annual rate of 2.5 percent during the same period.

R&D (most of which is development) accounts for 13 percent of all money authorized to be spent by the Federal Government on defense activities in 2000, according to the Federal budget authority. In contrast, R&D accounts for only 3 percent of the Federal nondefense budget authority, though many nondefense functions have much higher proportions. (See text table 2-2.) With regard to nondefense objectives (or "budget functions"), R&D accounts for 73 percent of the funds for general science—nearly all of which (95 percent) is devoted to basic research. (See text table 2-3.) R&D accounts for 67 percent of the funds for space research and technology, most of which (78 percent) is devoted to applied research and development. Among funds for health, R&D represents 10 percent, most of which (54 percent) is devoted to basic research and nearly all of which is directed toward NIH programs.

Figure 2-4.
Federal R&D funding, by budget function



NOTES: "Other" includes all nondefense functions not separately graphed, such as agriculture and transportation. The 1998 increase in general science and decrease in energy resulted from a reclassification.

See appendix table 2-23. *Science & Engineering Indicators – 2000*

[8]The sample design for estimating industry R&D expenditures was revised for 1991 and later years. The effect of the change in industry's sample design was to reduce the Federal share of the national R&D total to 38 percent in 1991, down from the 41 percent share previously published for 1991. For more information on these survey changes and their effects on R&D estimates, see Appendix A in NSF (1999c).

[9]These percentage share calculations of defense-related R&D activities are based on Federal budget authorization totals, not on data reported by the performers of R&D. Although funding is designated in the budget authority, it is actually provided through appropriations, not authorizations. In congressional terminology, authorizations are only guidelines, suggestions, or ceilings for appropriations and do not result in any money actually being spent. Only appropriations can provide money.

21st Century Research Fund and Earlier Concepts

The discussion and statistics on Federal funding of R&D provided in this chapter are based on two economic measures of R&D that have significant historical precedence: the Federal "budget authority" for R&D and accounts of "Federal funds" for R&D. Statistics on the R&D budget authority are provided in the Budget of the United States Government, though more detailed information on the budget authority for R&D is acquired through the NSF survey *Federal R&D Funding by Budget Function.* Statistics on Federal funds for R&D are acquired through the NSF survey *Federal Funds for Research and Development.* These two Federal surveys, along with other NSF surveys of the academic, industrial, and nonprofit sectors, provide the statistical information on R&D levels presented in this chapter.

The budget authority and Federal funds differ in definition. The budget authority is the primary source of legal authorization to enter into financial obligations that will result in outlays. Budget authority is most commonly granted in the form of appropriations laws enacted by Congress with the approval of the President. In contrast, Federal funds are measured in the form of obligations, which represent the amounts for orders placed, contracts awarded, services received, and similar transactions during a given period, regardless of when the funds were appropriated or when future payments are required.

In recent years, however, alternative concepts have been used to isolate and describe fractions of Federal support that could be associated with scientific achievement and technological progress. In a 1995 report (NAS 1995), members of a National Academy of Sciences committee proposed an alternative method of measuring the Federal Government's science and technology (S&T) investment. According to the committee members, this approach—titled the Federal Science and Technology (FS&T) budget—might provide a better way to track and evaluate trends in public investment in R&D. (This concept was discussed in *Science & Engineering Indicators—1998.*) The FS&T concept differed from Federal funds for research in a variety of ways: It was never defined in precise terms; unlike Federal funds, it did not include major systems development supported by DOD and DOE; and it contained not only research but also some development and some R&D plant.*

In the FY 1999 budget, a new concept—the "Research Fund for America" (RFA)—was introduced, which reflected the Administration's interest in addressing the FS&T concept previously proposed by the Academy. Unlike the FS&T budget, however—which was constructed from components of the R&D budget—the RFA was constructed out of easily-trackable programs and included some non-R&D programs, such as NSF education programs and staff salaries at the National Institutes of Health (NIH) and NSF. The RFA consisted of only civilian (nondefense) R&D; it captured 94 percent of civilian basic research, 72 percent of civilian applied research, and 51 percent of civilian development. With regard to specific Federal agencies, the RFA included R&D supported by the Department of Health and Human Services (HHS), NSF, DOE, the Department of the Interior (DOI), the Environmental Protection Agency (EPA), and the Department of Veterans Affairs; R&D supported by various offices under the Department of Agriculture (USDA), the Department of Commerce (DOC), the National Aeronautics and Space Administration (NASA), and the Department of Education; and R&D associated with the "Climate Change Technology Initiative" interagency project. Not included under the RFA concept was R&D supported by DOD, the Department of Housing and Urban Development (HUD) (not otherwise included in the climate change technology initiative), the Department of Justice (DOJ), the Department of Labor (DOL), and the Department of Transportation (DOT).

The FY 2000 Budget refers to the concept "21st Century Research Fund," which is a slight modification of the RFA. It expands the RFA to include basic and applied research in defense, adds certain programs in transportation, and removes the HUD portion of the climate change technology initiative. Thus, the 21st Century Research Fund includes research supported by HHS, NSF, DOE, NASA, DOD, USDA, DOC, DOI, EPA, the Department of Veterans Affairs, the Department of Education, and DOT but does not include research supported by HUD, DOJ, DOL, the Treasury Department, the Smithsonian Institution, and other agencies with relatively low levels of research support.

The 21st Century Fund's estimated total budget authority for FY 1998, according to the 2000 Budget of the United States Government, is $33.8 billion. It captures approximately 95 percent of total basic research and 75 percent of total applied research. Like the RFA, the 21st Century Fund includes some development funds, as well as the same non-R&D programs as the RFA. Consequently, it is not comparable to total research funding as defined and reported in this chapter.

*For additional discussion on the differences between R&D, FS&T, and the programs in the 21st Century Fund, see Chapter 6 of AAAS (1999b).

At first glance, the R&D budget authority for energy appears to have declined rapidly in recent years—in particular, from $2.4 billion in 1997 to only $0.9 billion in 1998. (See figure 2-4.) This effect, however, was the result of reclassification, not an actual decline in economic resources devoted to energy R&D. Beginning in FY 1998, several DOE programs were reclassified from "energy" to "general science," so the decline from $2.4 billion to $0.9 billion in energy R&D was offset by an increase in general science from $2.9 billion to $4.4 billion. (See appendix table 2-23.)

Federal Support by Functional Categories

Defense-related R&D, as a proportion of the Nation's total R&D, has undergone substantial shifts. From 1953 to 1959, defense-related R&D rose from 48 percent to 54 percent; it then declined to a relative low of 24 percent in 1980. From 1980 to 1987, it climbed again to 31.8 percent, but then it declined again to a low of 16 percent in 1998.[10] (See figure 2-5.)

[10]These shares by national objective represent a distribution of performer-reported R&D data. They are distinct from the budget authority shares reported above, which are based on the functional categories that constitute the Federal budget.

Text table 2–2.
R&D as a percentage of Federal budget authority, by function: FY 2000

	Millions of dollars		Percent
Budget function	R&D total (preliminary 2000)	Federal total	R&D share
Total	75,415	1,781,050	4.2
On-budget	75,415	1,441,914	5.2
National defense	37,710	280,800	13.4
Nondefense (on-budget)	37,704	1,161,114	3.2
Health	15,824	155,483	10.2
Space research and technology	8,422	12,509	67.3
Energy[a]	1,348	(2,260)	NA
General science	4,951	6,771	73.1
Natural resources and environment	1,944	23,952	8.1
Transportation	1,840	53,423	3.4
Agriculture	1,522	14,148	10.8
All other	1,853	897,088	0.2

NA = Not applicable

NOTES: Because of rounding, components may not add to totals shown. Data are derived from the Administration's 1999 budget proposal. On-budget totals are for all Federal Government transactions except those of the Social Security trust funds (Federal Old-Age and Survivors Insurance and Federal Disability Insurance Trust Funds) and the Postal Service.

[a]The budget authority for Energy is negative because of offsetting receipts from sales of the Strategic Petroleum Reserve.

SOURCES: National Science Foundation, Division of Science Resources Studies, and Office of Management and Budget, *The Budget for Fiscal Year 2000*, Historical Tables, and National Science Foundation/Division of Science Resources Studies, *Federal R&D Funding by Budget Function: Fiscal Years 1998–2000*.

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Text table 2–3.
Budget authority for R&D by function and character of work: Anticipated levels for FY 2000
(Millions of dollars)

Budget function	Basic research	Applied research and development	R&D total
Total	18,101	57,314	75,415
National defense	1,152	36,559	37,710
Nondefense (total)	16,949	20,755	37,704
Health	8,590	7,234	15,824
Space research and technology	1,841	6,581	8,422
Energy	46	1,302	1,348
General science	4,710	241	4,951
Natural resources and environment	175	1,769	1,944
Transportation	634	1,206	1,840
Agriculture	736	786	1,522
All other	218	1,636	1,853

NOTE: Because of rounding, components may not add to totals shown.

SOURCES: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Federal R&D Funding by Budget Function: Fiscal Years 1998–2000*, and unpublished tabulations.

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Space-related R&D funding, as a percentage of total R&D funding, reached a peak of 22 percent in 1965, during the height of U.S. efforts to surpass the Soviet Union in space travel. It declined after that, to a low of 3 percent in 1984 and 1986. By 1990 it was back up to 4 percent, and it has remained between 4 and 5 percent since. Federal support for nondefense/nonspace R&D programs, as a percentage of total U.S. R&D, has been declining steadily since 1994, when it was 12 percent. It was 10 percent in 1998—the lowest since 1961 (when it was 9 percent).

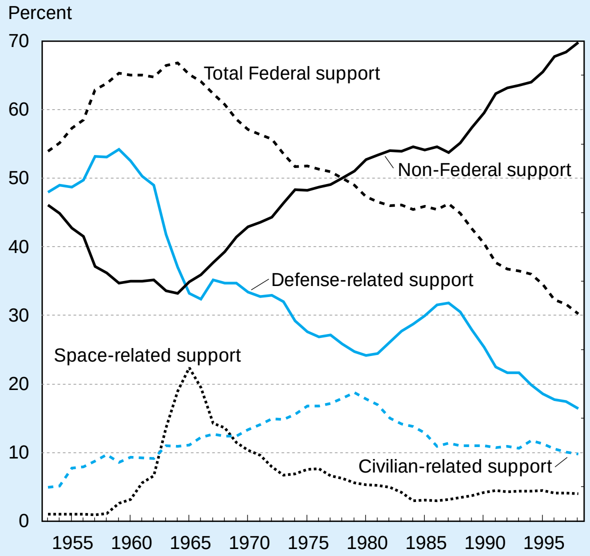
R&D by Federal Agency

According to preliminary data provided by Federal agencies, in FY 1999 DOD was the source of 75 percent of all Federal R&D obligations to industry, excluding industry-administered FFRDCs. (See appendix table 2-38.) Nearly all (94 percent) of these funds supported development work. Two other agencies—NASA and DOE—provide most of the other Federal R&D funds that industry receives.

HHS accounted for 59 percent of all Federal R&D obligations to universities and colleges, excluding university-administered FFRDCs, in FY 1999. Most of HHS's R&D support (56 percent) is directed toward academia; 21 percent is spent internally, mostly in NIH laboratories. HHS also accounts for 67 percent of all Federal R&D obligations for nonprofit organizations in 1999. Approximately 5 percent of HHS R&D obligations go to industrial firms.

NSF and DOD are the other leading supporters of R&D conducted in academic facilities. Eighty-one percent of NSF's

Figure 2-5.
Trends in Federal and non-Federal R&D expenditures as a percentage of total R&D: 1953–98



See appendix table 2-19. *Science & Engineering Indicators – 2000*

R&D budget supports projects at universities and colleges. Most of the remainder is divided among other nonprofit organizations (7 percent), university-administered FFRDCs (6 percent), and industry (5 percent). DOD provides only 4 percent of its R&D support to universities and colleges; it provides 70 percent to industry and 23 percent to Federal intramural activities. In contrast, DOE provides 9 percent of its support to universities, 22 percent to industry, 12 percent to Federal intramural activities, and 37 percent to FFRDCs administered by universities and colleges.

Of all Federal obligations to FFRDCs in FY 1999, DOE accounted for 61 percent, NASA accounted for 18 percent, and DOD accounted for 14 percent. More than half (56 percent) of DOE's R&D support is directed to FFRDCs.

Unlike all other Federal agencies, USDA, DOC, and DOI spend most of their R&D obligations internally. Most of the R&D supported by these agencies is mission-oriented and is conducted in laboratories run by the Agricultural Research Service, the National Institute for Standards and Technology (NIST), and the U.S. Geological Survey (USGS).

Federal R&D obligations are concentrated in a small number of agencies. Six Federal agencies had R&D obligations of more than $1 billion in FY 1998 (out of total Federal R&D obligations of $72 billion). These agencies, in descending order of R&D obligations, are DOD (48.3 percent of the total), HHS (19.02 percent), NASA (13.7 percent), DOE (8.1 percent), NSF (3.3 percent), and USDA (2.0 percent). (See figure 2-6 and text table 2-4.)

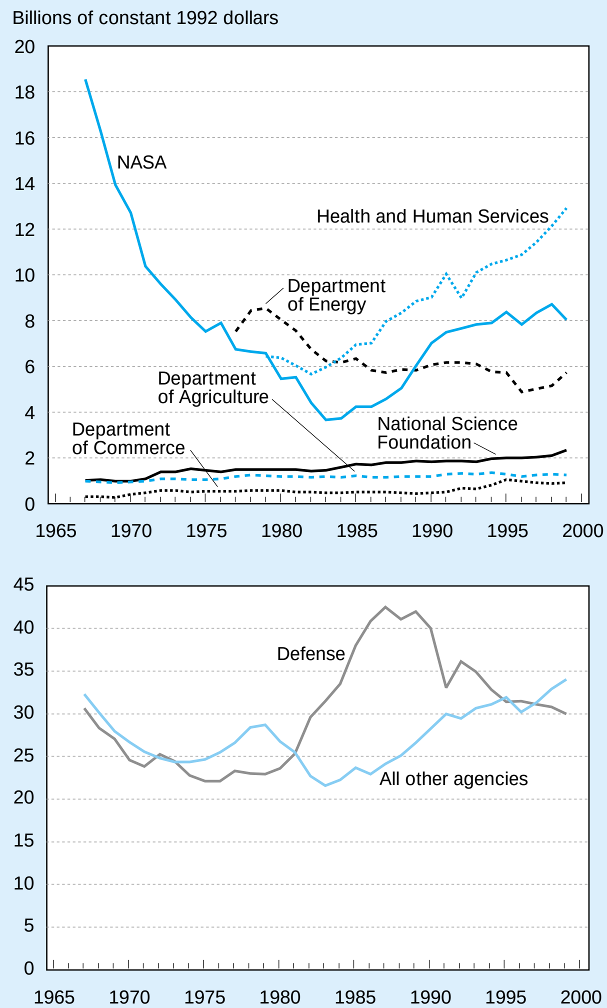
In contrast to total R&D obligations, only three agencies had intramural R&D expenditures that exceeded $1 billion in 1998, including costs associated with planning and administering extramural R&D programs: DOD, HHS (which includes NIH), and NASA. These three agencies together accounted for 81 percent of all Federal R&D obligations for 1998 and 77 percent of Federal intramural R&D.

All agencies, including those that fund R&D, are subject to evaluation and scrutiny according to the Government Performance and Results Act (GPRA) of 1993. (See sidebar, "GPRA and Federal Support for R&D.")

Federal Support to Academia

The Federal Government has long provided the largest share of R&D funds used by universities and colleges. In the early 1980s, Federal funds accounted for roughly two-thirds of the academic total. By 1991, however, that share had dropped to 59 percent, and it has remained between 59 and 60 percent since. Although this share of funding has not changed much in recent years, the actual amount of funding, in real terms, grew an average of 4.8 percent per year between 1985 and 1994 and 2.8 percent between 1994 and 1998. (For more information on academic R&D, see chapter 6.)

Figure 2-6.
National R&D obligations, by selected agency



See appendix table 2-26. *Science & Engineering Indicators – 2000*

GPRA and Federal Support for R&D

In response to the Clinton Administration's effort to move toward a government that works better and costs less, Congress passed the Government Performance and Results Act (GPRA) of 1993. GPRA aims to shift the focus of Federal agencies away from traditional concerns such as staffing and the level of services provided and toward results. Specifically, GPRA seeks to improve Federal planning and management, increase accountability for and assessment of results, and provide better information for congressional and agency decisionmaking. To accomplish these and related goals, GPRA requires every Federal agency to prepare detailed, multiyear strategic plans, annual performance plans, and annual performance reports. These documents give agencies formal tools with which to set forth goals, to prepare plans to meet those goals, and to assess and measure progress and accomplishments on a regular and systematic basis.

GPRA poses a particular challenge for agencies that must assess the scientific research programs they fund. In fact, the General Accounting Office (GAO) has found that measuring the discrete contribution of a Federal initiative to a specific program result is particularly challenging for regulatory programs; scientific research programs; and programs that deliver services to taxpayers through third parties, such as state and local governments (GAO 1997a). Regarding research programs, GAO points out that the amount of money spent on R&D has been used as the primary indicator of how much research is being performed in a given area—but that such an input indicator does not provide a good indication of the outcomes (results) of the research. In a recent report, GAO notes:

> Experts in research measurement have tried for years to develop indicators that would provide a measure of the results of R&D. However, the very nature of the innovative process makes measuring the performance of science-related projects difficult. For example, a wide range of factors determine if and when a particular R&D project will result in commercial or other benefits. It can also take many years for a research project to achieve results…Experiences from pilot efforts made under the Government Performance and Results Act have reinforced the finding that output measures are highly specific to the management and mission of each Federal agency and that no single indicator exists to measure the results of the research (GAO 1997b, 2–3).

The Committee on Science, Engineering, and Public Policy (COSEPUP)—a joint committee of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine—wrote a report titled *Evaluating Federal Research Programs*: *Research and the Government Performance and Results Act* (COSEPUP 1999). As the title suggests, the report addressed how Federally supported research should be evaluated for its compliance with GPRA requirements. According to the report, "Agencies are required to develop a strategic plan that sets goals and objectives for at least a 5-year period, an annual performance plan that translates the goals of the strategic plan into annual targets, and an annual performance report that demonstrates whether targets are met" (COSEPUP 1999, 1).

Through its expert analysis of the nature of Federal research support and its understanding of GPRA requirements, COSEPUP reached the following conclusions:

- Both applied research and basic research…can be evaluated meaningfully on a regular basis.
- Agencies must evaluate their research programs by using measurements that match the character of research.
- The most effective means of evaluating Federally funded research programs is expert review.
- Agencies must pay increased attention to their human-resource requirements in terms of training and educating young scientists and engineers and in terms of providing an adequate supply of scientists and engineers to academe, industry, and Federal laboratories.
- Mechanisms for coordinating research programs in multiple agencies whose fields or subject matters overlap are insufficient.
- The development of effective methods for evaluating and reporting performance requires the participation of the scientific and engineering community, whose members will necessarily be involved in expert review (COSEPUP 1999, 4–8).

In accordance with these findings, COSEPUP made the following recommendations:

- Research programs should be described in strategic and performance plans and evaluated in performance reports.
- For applied research programs, agencies should measure progress toward practical outcomes. For basic research programs, agencies should measure quality, relevance, and leadership.
- Federal agencies should use expert review to assess the quality of research they support, the relevance of that research to their mission, and the leadership of that research.
- Both research and mission agencies should describe in their strategic and performance plans the goal of developing and maintaining adequate human resources in fields critical to their missions both at the national level and in their agencies.
- Although GPRA is conducted agency-by-agency, a formal process should be established to identify and coordinate areas of research that are supported by multiple agencies. A lead agency should be identified for each field of research and that agency should be responsible for assuring that coordination occurs among the agencies.
- The science and engineering community can and should play an important role in GPRA implementation (COSEPUP 1999, 8–11).

Text table 2–4.
Federal R&D obligations, total and intramural by agency: FY 1998

Agency	Total R&D obligations (millions of current dollars)	Total R&D obligations as a share of Federal total (percent)	Intramural R&D (millions of current dollars)	Percent of agency R&D obligations that are intramural[a]	Percent change in real intramural R&D from previous year[b]
Department of Defense	34,832.6	48.30	7,750.6	22.25	–6.1
Dept of Health & Human Services, total	13,717.8	19.02	2,957.2	21.56	9.3
National Aeronautics & Space Admin	9,850.7	13.66	2,462.7	25.00	4.4
Department of Energy	5,833.1	8.09	535.1	9.17	24.3
National Science Foundation	2,356.9	3.27	14.4	0.61	3.9
Department of Agriculture, total	1,441.9	2.00	954.9	66.23	3.0
Department of Commerce, total	978.7	1.36	695.1	71.02	3.4
Department of Transportation, total	664.7	0.92	265.8	39.99	36.8
Department of the Interior, total	613.3	0.85	541.9	88.36	3.3
Environmental Protection Agency	606.0	0.84	289.3	47.74	11.1
Department of Veterans Affairs	299.3	0.42	299.3	100.00	17.0
Department of Education	211.8	0.29	9.8	4.63	5.3
Agency for International Development	183.9	0.26	21.0	11.42	–7.8
Smithsonian Institution	134.0	0.19	134.0	100.00	1.9
Department of Justice, total	102.9	0.14	42.2	41.01	0.2
Department of the Treasury, total	74.2	0.10	45.3	61.05	15.7
Social Security Administration	56.1	0.08	6.3	11.23	24.5
Nuclear Regulatory Commission	50.7	0.07	14.0	27.61	-9.0
Department of Labor, total	46.8	0.06	16.8	35.90	25.8
Dept of Housing & Urban Development	39.6	0.05	25.0	63.13	16.5
U.S. International Trade Commission	5.8	0.01	5.8	100.00	0.5
Tennessee Valley Authority	2.9	0.00	2.9	100.00	–67.8
Library of Congress	2.5	0.00	2.5	100.00	–11.8
Department of State	1.0	0.00	0.3	30.00	–1.2
Other Agencies[c]	6.9	0.01	5.4	78.26	11.2
Entire Federal Government[d]	72,114.1	100.00	17,097.6	23.71	1.0

[a]Intramural activities include actual intramural R&D performance and the costs associated with the planning and administration of both intramural and extramural programs by Federal personnel.

[b]Based on fiscal year GDP implicit price deflators for 1997 and 1998. (See appendix table 2-1.)

[c]Includes: Appalachian Regional Commission, Consumer Product Safety Commission, Federal Communications Commission, Federal Trade Commission, National Archives and Records Administration, U.S. Arms Control and Disarmament Agency, and U.S. Information Agency.

[d]Numbers do not total exactly, due to rounding.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Survey of Federal Funds for Research and Development: Fiscal Years 1997, 1998, and 1999.*

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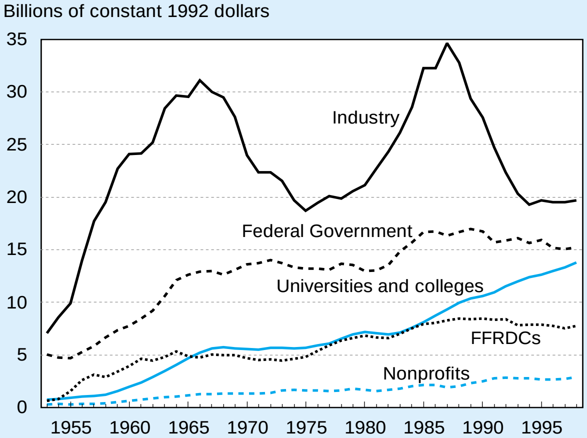
R&D performance in 1998 by university-administered FFRDCs was $5.5 billion, or approximately 2.4 percent of the national R&D effort. These FFRDCs accounted for 17.3 percent of total 1998 academic R&D performance (universities and colleges plus academically administered FFRDCs). From 1974 to 1980, R&D at academically administered FFRDCs grew by 8.5 percent per year in real terms. This increase largely mirrored the Federal emphasis on energy programs. Since 1980, the Federal shift away from energy concerns has resulted in much slower growth in academically administered FFRDC R&D performance—only 1.2 percent per year in real terms.

Federal Funding to Other Sectors

Trends in Federal funding to industry, FFRDCs, and other nonprofit organizations have varied considerably over time. (See figure 2-7.) The greatest fluctuation has been Federal funds to industry (excluding industry-administered FFRDCs), which rose from a low of $7.1 billion (in constant 1992 dollars) in 1953 (at the beginning of a time series)[11] to $31.1 billion in 1966, fell to $18.7 billion in 1975, rose sharply

[11]The 1953 value is actually an overestimate because the 1953 and 1954 figures for Federal support to industry include support to industry-administered FFRDCs, whereas the figures for subsequent years do not. (See appendix table 2-6.)

Figure 2-7.
Federal R&D support, by performing sector



See appendix tables 2-6 and 2-7.

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thereafter to $34.6 billion in 1987, and then fell sharply again to $19.3 billion in 1994. From 1994 to 1998, however, Federal support to industry has been relatively unchanged—ranging from $19.3 to $19.7 billion (in constant 1992 dollars). These trends reflect the historical shifts in Federal priorities on defense-, space-, heath-, and energy-related R&D. (See sidebar, "FY 1998 is Final Year for Tracking of Independent Research and Development Defense Spending.")

Federal funding to FFRDCs and nonprofit organizations has undergone much less fluctuation since 1953. Federal support to nonprofit organizations displayed steady growth overall for the 1953–98 period. Support to FFRDCs grew substantially in real terms between 1955 and 1963, experienced almost no real growth between 1963 and 1981, grew substantially again between 1981 and 1985, and has since experienced a gradual decline in real funding. (See figure 2-7.)

Federal financing for industrial R&D, including industry FFRDCs, has varied markedly across time and across different industries. The Federal Government provided $23.9 billion for industry R&D in 1997 (the most recent year for which detailed data by industrial category are available). Aerospace companies (or the industrial sector "aircraft and missiles") alone received 44 percent of all Federal R&D funds provided to all industries. Consequently, 65 percent of the aerospace industry's R&D dollars came from Federal sources; the remaining 35 percent came from those companies' own funds. In comparison, the drugs and medicines sector in 1997 financed 100 percent of its R&D from company funds; machinery financed 99 percent of its R&D from company funds, professional and scientific instruments financed 67 percent from company funds, transportation equipment other than aircraft and missiles financed 90 percent from company funds, business services financed 97 percent from company funds, and engineering and management services financed 64 percent from company funds.[12]

Federal funding of R&D in aircraft and missiles has declined between 1985 and 1997, both as a percentage of total Federal support to all industries and as a percentage of the aircraft and missiles sector's total R&D. (See figure 2-8.) Nevertheless, the aircraft and missiles sector has continued to receive more Federal support than any other industrial sector in actual dollars. The exact amounts, however, seem somewhat in question. Classifying and tracking Federal support for defense-related industrial R&D appears to be extremely difficult. (See "Accounting for Defense R&D: Gap Between Performer- and Source-Reported Expenditures.")

Federal R&D support for professional and scientific instruments rose sharply between 1988 and 1997—from 0.6 percent of all Federal support to industry to 19 percent of all Federal support. Likewise, Federal support in this area grew from only 3 percent of the sector's total R&D performance in 1988 to 33 percent 1997. (See figure 2-8.)

Interestingly, Federal funds devoted to the nonmanufacturing sector grew from 9 to 17 percent between 1985 and 1997. Because total Federal support to industry declined in real terms over this period, however, Federal support to R&D in nonmanufacturing as a percentage of all R&D in nonmanufacturing declined markedly over the same period—from 34 percent in 1985 to 11 percent in 1997.

Also declining over this period—both as a percentage of the Federal contribution and as a percentage of each of the sectors' total R&D performance—was Federal support for R&D in electrical equipment, transportation equipment other than aircraft and missiles, and machinery. (See figure 2-8.)

Federal Support for Small Business R&D

In addition to traditional government procurement for R&D that tends to be performed by large companies, Federal R&D support is also provided through its Small Business Innovation Research (SBIR) Program. Created in 1982 to strengthen the role of small firms in Federally supported R&D, the SBIR Program presently consists of 10 independently administered Federal agency programs; it is the country's largest merit-based competitive grants program available to small businesses. Through FY 1997, the SBIR Program had directed nearly 46,000 awards worth more than $7.5 billion in R&D support to thousands of qualified small high-technology companies on a competitive basis. Under this program—which is coordinated by the Small Business Administration (SBA) and is in effect until the year 2000—when an agency's external R&D obligations (those exclusive of in-house R&D performance) exceed $100 million, the agency must set aside a fixed percentage of such obligations for SBIR projects. This per-

[12]The 100 percent company funding for the drugs and medicines sector does not include the benefits this sector receives from R&D financed by NIH.

FY 1998 is Final Year for Tracking of Independent Research and Development Defense Spending

In addition to the Federal R&D obligations discussed in this chapter, DOD's Independent Research and Development (IR&D) Program enables industry to obtain Federal funding for R&D conducted in anticipation of government defense and space needs. Because private contractors initiate IR&D themselves, IR&D is distinct from R&D performed under contract to government agencies for specific purposes. IR&D allows contractors to recover a portion of their in-house R&D costs through overhead payments on Federal contracts on the same basis as general and administrative expenses.*

Until 1992, all reimbursable IR&D projects were to have "potential military relevance." Because of the concern that defense cutbacks would reduce civilian R&D—not only in the level of commercial spillovers from weapons research but, more important, in dramatically reduced DOD procurement from which IR&D is funded—the rules for reimbursement have been successively eased and the eligibility criteria broadened. Reimbursement is now permissible for a variety of IR&D projects of interest to DOD, including those intended to enhance industrial competitiveness, develop or promote dual-use technologies, or provide technologies that address environmental concerns. DOD reimbursed $1.6 billion in 1998. (NASA also reimburses firms for IR&D costs, but those amounts are significantly less—about 5 to 10 percent of the DOD reimbursements.) As an equivalent proportion of DOD's direct industrial R&D support, IR&D fell from 12 percent in 1984 to less than 7 percent in 1998, although the latter figure is undoubtedly on the low side as a result of accounting and statistical changes. (See appendix table 2-43.) Prior to 1993, contractors with auditable costs of $40 million or more were included in the IR&D statistics. Since then, the threshold has included only firms with auditable costs of more than $70 million. As a result of auditing and reimbursement policy changes that allow practically all of industry's IR&D claims, future collection of IR&D data is not expected.

*In national statistics on R&D performance and funding, industrial firms are requested to report IR&D expenditures as industry-funded, industry-performed R&D. Ultimately, firms expect to be reimbursed for most—but not all—of these expenditures. Federal agencies do not include IR&D obligations in their reported R&D totals. For example, IR&D reimbursements to industry are paid out of DOD's procurement accounts, not its research, development, test, and evaluation (RDT&E) accounts.

centage initially was set at 1.25 percent, but under the Small Business Research and Development Enhancement Act of 1992, it rose incrementally to 2.5 percent by 1997.

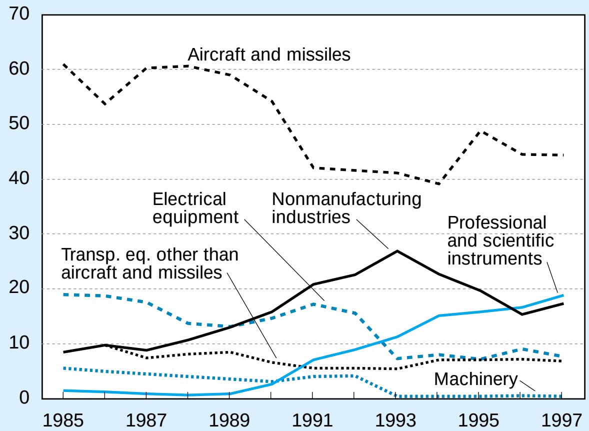
To obtain funding, a company applies for a Phase I SBIR grant. The proposed project must meet an agency's research needs and have commercial potential. If approved, grants of up to $100,000 are made to allow evaluation of the scientific and technical merit and feasibility of an idea. If the concept shows potential, the company can receive a Phase II grant of up to $750,000 to develop the idea further. In Phase III, the innovation must be brought to market with private-sector investment and support; no SBIR funds may be used for Phase III activities.

Ten Federal agencies participated in the SBIR Program in 1997, making awards totaling $1.1 billion—an amount equivalent to 1.6 percent of all government R&D obligations (2 percent of Federally funded R&D performed outside of government labs). The total amount obligated for SBIR awards in 1997 was 20 percent more than in 1996—a result of legislatively required increases in R&D amounts agencies must earmark for SBIR. Since 1992, SBIR funding has more than doubled, while total Federal R&D funding has increased by just 5 percent. In FY 1997, 74 percent of total SBIR funds were disbursed through Phase II grants, although 71 percent of the grants awarded were Phase I grants (3,371 of 4,775 awards). Approximately 51 percent of all SBIR obligations were provided by DOD, mirroring this agency's share of the Federal R&D extramural funding total. (See appendix table 2-44.)

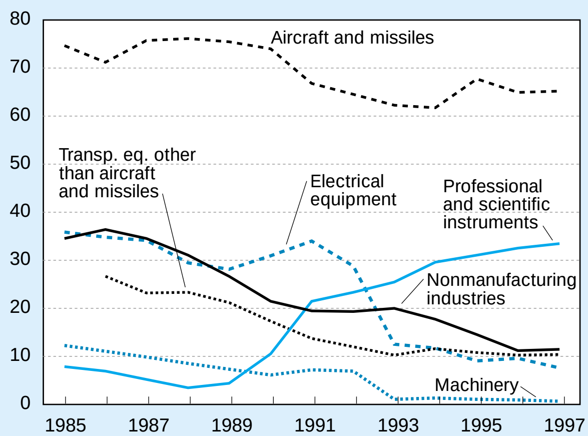
Except for evaluations undertaken by GAO, there have been few independent assessments of the overall effectiveness of the SBIR Program. Where such assessments do exist, however, there is general agreement that the quality of funded research proposals is high and that the value of the program in fostering small business technology-led economic growth is apparent. (See, for example, GAO 1997a and 1998.) In a recent assessment of program administrators' perspectives on SBIR strengths and weaknesses, Federal and state partners agreed that SBIR is invaluable as an effective catalyst for the development of technological innovations by small businesses. Indicative of this viewpoint, all but two states—Kentucky and Pennsylvania—currently have some structured SBIR promotion or assistance effort underway (SSTI 1999b). Most state initiatives focus on the early stages of the SBIR process—for example, creating awareness of the program and supporting pre-Phase 1 activities. (See text table 2-5.)

SBA classifies SBIR awards into various technology areas. In terms of all SBIR awards made during the 1983–97 period, the fine technology areas receiving the largest (value) share of awards were advanced materials, electronics device performance, electromagnetic radiation, and computer communications systems. More broadly, more than one-fourth of all awards made from 1983 to 1997 were electronics-related, and roughly one-sixth involved computers. (See figure 2-9.) Computer- and electronics-related projects received more than 70 percent of their support from DOD and NASA. One-seventh of all SBIR awards went to life sci-

Figure 2-8.
Federal support for R&D in selected industries as a percentage of all Federal support to industrial R&D



Federal support for R&D in selected industries as a percentage of all total R&D performed in those industries



See appendix tables 2-53, 2-54, and 2-55.

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ences research; the bulk of this funding was provided by HHS (SBA 1998).

U.S. Federal and State R&D Tax Credits

Federal R&D Tax Credits

The U.S. government has tried various policy instruments in addition to direct financial R&D support to indirectly stimulate corporate research spending. Proponents of such measures commonly note that, especially as Federal discretionary spending for R&D is squeezed, incentives must be used to invigorate U.S. investment in private-sector innovation to expand U.S. global leadership in high technology. The most notable of these efforts have been tax credits on incremental

Text table 2–5.
Number of states offering different types of SBIR assistance and services: 1998

Stage in the SBIR Program	Service or Activity	Number
Awareness	Outreach conference	45
	Information clearinghouse	37
	Website	35
	Proactive topic match	18
	Marketing & press release	17
	SBIR newsletter	10
Phase 0	Proposal writing workshops	37
	Proposal assistance	31
	Proposal critique	30
	Reactive topic match	22
	Project team assembly	21
	Literature searches	16
	Phase 0 grants	11
	Marketing topics to agencies	10
Phase I	Trouble shooting for winners	20
	Mentor networks	16
	Winner recognition	11
	Local focus groups	6
	Phase 1 matching funds	5
Pre-Phase II	Strategic alliances	28
	Bridge financing	8
Phase II and beyond	Commercialization assistance	25
	Technology transfer	19
	Phase III investments	5
	Phase II matching funds	2

SOURCE: State Science and Technology Institute (SSTI), *State and Federal Perspectives on the SBIR Program*, Westerville, OH: SSTI, 1999.

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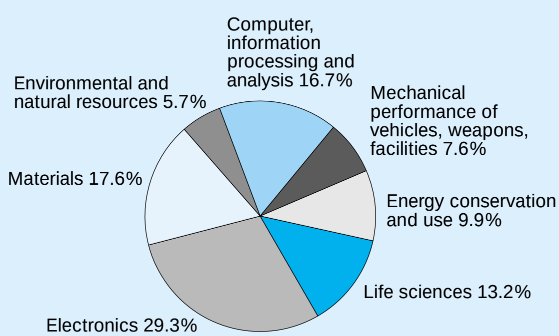
Figure 2-9.
Small business innovation research awards, by technology area: 1983–97



SOURCE: Small Business Administration, Annual Report–FY 1997.

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research and experimentation (R&E) expenditures.[13] The credit was first put in place in 1981; it has been renewed nine times, most recently through the end of June 1999.[14] Although the computations are complicated, the tax code provides for a 20 percent credit for a company's qualified R&D amount that exceeds a certain threshold.[15] Since 1986, companies have been allowed to claim a similar credit for basic research grants to universities and other qualifying nonprofit institutions, although otherwise deductible R&E expenditures are reduced by the amount of the basic research credit. This basic research provision generally has gone unutilized.[16]

According to a report prepared for the Joint Economic Committee of the U.S. Congress (based on information from the Internal Revenue Service Statistics of Income publications), more than 12,000 firms use the tax credit (Whang 1998b). From tax years 1991 through 1995 (the latest year of available data), an average of 12,472 firms filed claims totaling $1.85 billion each year, although not all claims are allowed and not all of the allowed credits can be taken immediately. (Thus, the dollar value of R&E tax credits actually received by firms is unknown.) In dollar terms, the largest credits are claimed by large manufacturers—especially pharmaceuticals, motor vehicles, aircraft, electronics and computer firms. Companies with more than $250 million in assets account for three-quarters of the dollar value of all credit claims. On the other hand, three-quarters of credit claimants have assets of $25 million or less, and many claims are filed by medium-sized manufacturers and service providers.

Budget Impact of Federal Tax Credits

To determine the budgetary effect of the credit, the Treasury Department annually calculates estimates of foregone tax revenue (tax expenditures) resulting from preferential tax provisions, including the R&E tax credit. As one such measure, Treasury provides outlay-equivalent[17] figures that allow a comparison of the cost of this tax expenditure with the cost of a direct Federal R&D outlay. Between fiscal years 1981 and 1998, an outlay-equivalent of more than $32 billion was provided to industry through this indirect means. For FY 1998 alone, Treasury calculates an outlay-equivalent of $3.3 billion from the R&D tax credit. Consequently, these credits were equivalent to about 3.2 percent of direct Federal R&D support for the entire 1981–98 period and a record 4.7 percent of direct Federal obligations in FY 1998. (See figure 2-10 and appendix table 2-45.)

State R&D Tax Credits

The Federal Government is not the only source of fiscal incentives for increasing research. According to a survey of the State Science and Technology Institute (SSTI 1997a), 35 states offered some type of incentive for R&D activity in 1996. Many states offered an income tax credit modeled after the Federal R&E credit guidelines. Fifteen states applied the Federal research tax credit concepts of qualified expenditures or base years to their own incentive programs, although they frequently specified that the credit could be applied only to expenditures for activities taking place within the state. Other types of R&D incentives included sales and use tax credits and property tax credits.

[13]Not all R&D expenditures are eligible for such credit, which is limited to expenditures on laboratory or experimental R&D.

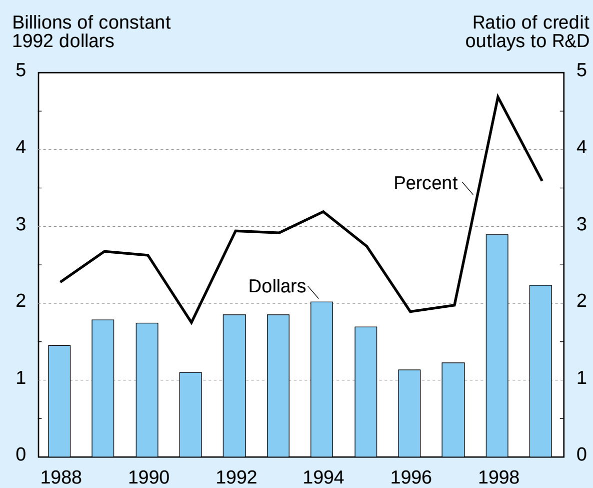
[14]Simply knowing whether the tax credit is in effect is a formidable challenge. Annual extensions have become the norm, and credits are often reinstated retroactively one or two months after the credit expires. At this writing, provision for the tax credit had once again lapsed, but congressional indications were that the credit would be renewed again, retroactively to July 1, 1999, and perhaps with a five-year extension.

[15]The complex base structure for calculating qualified R&D spending was put in place by the Omnibus Reconciliation Act of 1989. With various exceptions, a company's qualifying threshold is the product of a fixed-base percentage multiplied by the average amount of the company's gross receipts for the four preceding years. The fixed-base percentage is the ratio of R&E expenses to gross receipts for the increasingly distant 1984–88 period. Special provisions cover startup firms. An alternative credit was established in 1996 that is not dependent on a firm's incremental R&D. Instead, a 1.65 percent to 2.74 percent credit is awarded for all research expenses exceeding 1 percent of sales. The marginal value of this credit has provided minimal incentive for firms (Whang 1998a).

[16]In 1992 (the latest year for which any such data exist), firms applying for the R&E credit spent about $1 billion on research performed by educational and scientific organizations. After accounting for various qualification restrictions, the basic research credit contributed less than $200 million toward the R&E tax credit (OTA 1995; Whang 1998a).

[17]Specifically, the "outlay-equivalent" measure is the amount of outlay that would be required to provide the taxpayer the same after-tax income as would be received through the tax preference. These amounts tend to be greater than estimates of Federal "revenue losses" from the credit because the outlay program increases the taxpayer's pre-tax income.

Figure 2-10.
Budgetary impact of Federal research and experimentation tax credit: FYs 1988-99



See appendix table 2-45.

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State Government Support for R&D

The pivotal role of state governments in expanding regional economic growth through science and technology (S&T) development is a widely recognized, albeit relatively recent, phenomenon. Almost all states have established lead S&T offices; the existence of most of these offices can be traced only to the mid- to late 1980s (NSB 1991). During the 1990s, states increasingly have included an S&T component in their economic development plans. Many states have adopted statewide S&T strategic initiatives of varying levels of sophistication and complexity (SSTI 1997b). A review of "State of the State" speeches, inaugural addresses, and budget messages delivered by most governors in the early part of 1999 indicates a continuing high level of interest in S&T-based economic development (SSTI 1999a). Common to these plans is the acknowledged importance of:

- Maintaining and strengthening the R&D capacity of the states' colleges and universities;
- Encouraging "home grown" businesses by providing support to entrepreneurs and small technology-based firms; and
- Facilitating the incorporation of new technology into processes and products.

States have become particularly adept at leveraging funds and fostering university-industry partnerships.

NSF has sponsored intermittent surveys of state governments' R&D expenditures dating to the mid-1960s. Over the past 30 years, growth in state R&D support is readily apparent; it generally has been proportionate to changes in other R&D indicators. (See text table 2-6.) Between 1965 and 1995, total state R&D spending increased at an inflation-adjusted average annual rate of 3.3 percent, compared with nationwide R&D spending growth of 2.5 percent per year (NSF 1999d). State sources of state R&D spending grew by 3.4 percent annually, from $732 million (1992 dollars) in 1965 to $2.010 billion (1992 dollars) in 1995. Most of the remaining funds derived from Federal agency support to state agencies. In 1995, state sources for R&D expenditures were equivalent to 1.18 percent of total R&D spending in the United States—a figure similar to the percentages estimated for 1987 and 1977 (1.20 and 1.21 percent, respectively) and somewhat higher than the 1965 estimate (of 0.9 percent). As a percentage of GDP, state sources for R&D have ranged narrowly between 0.025 and 0.032 percent during the 1965–95 period for which there are data. These data also show that universities historically have received the lion's share of state-funded R&D. In 1995, 80 percent of all state R&D funds from state sources supported university activities—only slightly higher than their estimated 78 percent share in 1965.

According to a report by Battelle and the State Science and Technology Institute (Battelle/SSTI 1998), 45 percent of all R&D funds from state sources ($2.431 billion) in 1995 were in support of the "science and technology base" ($1.088 billion), which includes research capacity building. (See text table 2-7.) These funds were spent predominately in support of university-based research. The only functional categories other than "science and technology base" to receive 10 percent or more of states' R&D funds were "food, fiber, agriculture" ($305 million) and "health" ($244 million). Universities

Text table 2–6.
Trends in state government R&D expenditures
(Billions of constant 1992 dollars[a])

	1965	1977	1987	1995
Total state R&D spending[b]	0.884	1.451	2.093	2.336
State sources	0.732	1.112	1.830	2.010
Federal sources	0.144	0.299	0.242	0.240
Non-government sources[c]	0.008	0.040	0.020	0.086
State R&D indicators (percent)				
State R&D/U.S. R&D	1.09	1.58	1.37	1.37
State sources/U.S. R&D	0.90	1.21	1.20	1.18
State R&D/U.S. GDP	0.031	0.034	0.037	0.035
State sources/U.S. GDP	0.025	0.026	0.032	0.030

NOTE: Because of rounding, details may not add to totals. Excludes expenditures on R&D plant. Annual survey data in this table were adjusted data to permit direct comparisons.

[a]GDP implicit price deflators used to convert current dollars to constant dollars.

[b]Includes all funds under state government control. These include state sources such as direct appropriations and funds generated from state bonds, funds from the Federal Government that pass through state agencies, and leveraged funds from industry and other non-government sources.

[c]Non-government sources include industry and other non-state, non-Federal sources such as donations, endowments, and gifts from private individuals or foundations.

SOURCE: National Science Foundation, Division of Science Resources Studies, *What is the State Government Role in the R&D Enterprise?* Arlington, VA: 1999.

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Text table 2–7.
State sources of R&D expenditures, by functional purpose: FY 1995

	($ millions)	Percent
Total	2,431.1	100.0
Science & technology base	1,087.7	44.7
Food, fibre, agriculture	305.4	12.6
Health	243.7	10.0
Economic development	192.1	7.9
Other functions, n.e.c.	158.4	6.5
Environment	110.1	4.5
Education	101.9	4.2
Transportation	80.9	3.3
Natural resources	78.7	3.2
Energy	44.1	1.8
Community development	16.8	0.7
Income security/social services	9.4	0.4
Crime prevention/control	1.9	0.1

SOURCE: Battelle Memorial Institute and State Science and Technology Institute, *Survey of State Research and Development Expenditures FY 1995*. Columbus, OH: Battelle/SSTI, 1998.

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were the primary recipients for funding in both of these categories. "Health" was the single largest functional focus of R&D performed by state agencies; almost 25 percent of the $244 million state-funded state-performed R&D was health-related. R&D explicitly related to "economic development" accounted for 8 percent ($192 million) of total state R&D funding in 1995. Reflecting recent trends to use R&D in support of local business and economic growth, however, "economic development" accounted for 38 percent of state R&D funds to industry ($33 million of the $87 million provided) and 53 percent of state R&D funds to nonprofit organizations ($55 million of $105 million). By comparison, the functionally equivalent category of "economic growth and productivity" accounted for only 5 percent of state funding for R&D to all performers in 1987 and for 2.2 percent of total in 1977 (NSF 1999d).

Historical Trends in Non-Federal Support

R&D financing from non-Federal sources grew by 5.9 percent per year (controlling for inflation) between 1953 and 1980. Between 1980 and 1985, concurrent with gains in Federal R&D spending, it grew at an even faster rate of 7.4 percent per year in real terms. It then slowed to 4.1 percent between 1985 and 1990 and 2.9 percent between 1990 and 1995, but it was back up to 8.4 percent for the 1995–98 period.

Most non-Federal R&D support is provided by industry. Of the 1998 non-Federal support total ($160.2 billion), 93.4 percent ($149.7 billion) was company funded, representing a 8.7 percent increase over its 1997 level in real terms. Industry's share of national R&D funding first surpassed that of the Federal Government in 1980; it has remained higher ever since. From 1980 to 1985, industrial support for R&D, in real dollars, grew at an average annual rate of 7.6 percent. This growth was maintained through the mild 1980 recession and the more severe 1982 recession. (See figure 2-1.) Key factors behind increases in industrial R&D have included a growing concern with international competition, especially in high-technology industries; the increasing technological sophistication of products, processes, and services; and general growth in defense-related industries such as electronics, aircraft, and missiles.

Between 1985 and 1994, growth in R&D funding from industry was slower, averaging only 2.8 percent per year in real terms. This slower growth in industrial R&D funding was only slightly greater than the real growth of the economy over the same period (in terms of real GDP), which was 2.4 percent. In contrast, from 1994 to 1998, industrial R&D support grew in real terms by 8.9 percent per year, compared with a 3.4 percent growth rate for the economy overall.

As one might expect, however, growth of industrial R&D varied significantly among different industrial sectors.[18] The largest sectors in recent years have been chemicals and allied products, electrical equipment, machinery, nonmanufacturing, and transportation equipment. (See appendix tables 2-53 and 2-54.) Between 1985 and 1997, the industrial sectors with the highest rates of annual growth in real R&D performance, from non-Federal sources, have been nonmanufacturing (14.7 percent); paper and allied products (4.9 percent); electrical equipment (4.7 percent); and lumber, wood products, and furniture (4.3 percent). Industries experiencing the greatest annual declines (or negative growth) in R&D over the same period were stone, clay, and glass products (–5.3 percent); petroleum refining and extraction (–5.3 percent); primary metals (–2.5 percent); and food, kindred, and tobacco products (–0.9 percent). (See appendix table 2-54.)

R&D funding from other non-Federal sectors—academic and other nonprofit institutions and state and local governments—has been more consistent over time. It grew in real terms at average annual rates of 5.2 percent between 1980 and 1985, 8.2 percent between 1985 and 1990, 2.3 percent between 1990 and 1995, and 3.9 percent between 1995 and 1998. The level of $10.6 billion in funding in 1998 was 4.8 percent higher in real terms than the 1997 level. Most of these funds have been used for research performed within the academic sector.

Trends in R&D Performance

U.S. R&D/GDP Ratio

Growth in R&D expenditure should be examined in the context of the overall growth of the economy because, as a part of the economy itself, R&D is influenced by many of the same factors. Furthermore, the ratio of R&D expenditures to GDP may be interpreted as a measure of the Nation's commitment to R&D relative to other endeavors.

A review of U.S. R&D expenditures as a percentage of GDP over time shows an initial low of 1.36 percent in 1953 (when the NSF data series began), rising to its highest peak

[18]For studies of patterns of technological change among different industrial sectors, see, for example, Nelson (1995); Pavitt (1984); Utterback (1979).

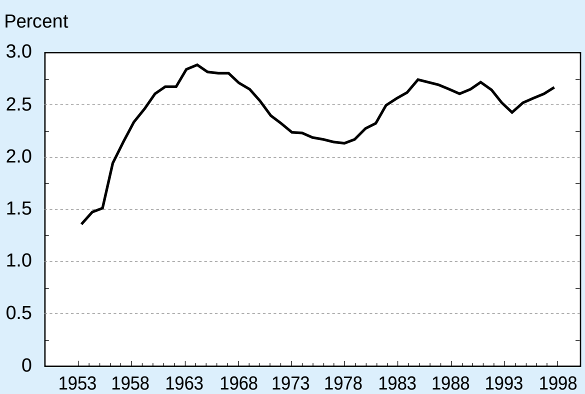
of 2.88 percent in 1964, followed by a gradual decline to 2.13 percent in 1978. (See figure 2-11.) R&D expenditures rose steadily again to a peak of 2.74 percent of GDP in 1985 and did not fall below 2.6 percent until 1993. In 1994, the ratio dropped to 2.43 percent—the lowest it had been since 1981. Starting in 1994, however, R&D/GDP has been on an upward trend as investments in R&D have outpaced growth on the general economy. As a result, the current ratio of 2.67 for 1998 is the highest since 1991.

The initial drop in the R&D/GDP ratio from its peak in 1964 largely reflected Federal cutbacks in defense and space R&D programs, although gains in energy R&D activities between 1975 and 1979 resulted in a relative stabilization of the ratio at around 2.2 percent. (See figure 2-11.) Over the entire 1965–78 period, the annual percentage increase in real R&D was less than the annual percentage increase in real GDP. In years when real R&D spending decreased during that period, real GDP also fell, but at a lower rate.

The rise in R&D/GDP from 1978 to 1985 was as much a result of a slowdown in GDP growth as to increased spending on R&D activities. For example, the 1980 and 1982 recessions resulted in a slight decline in real GDP, but there was no corresponding reduction in R&D spending. During previous recessions, changes in funding for R&D tended to match or exceed the adverse movements of broader economic measures.

R&D/GDP decreased from 2.74 percent in 1985 to 2.61 percent in 1989 but rose to 2.72 percent by 1991. (See figure 2-11.) Again, the ratio tended to fall when GDP experienced relatively fast real growth and rise when it experienced relatively slow real growth. Nevertheless, R&D itself was also affected. The share of R&D that was defense related dropped from 31.1 percent in 1985 to 22.6 percent in 1991. Commensurate with this change was the sharp fall in the share of R&D that was Federally funded—from 46.0 percent in 1985 to 37.8 percent in 1991. (See figure 2-3.) This decline in Federal funding was counterbalanced by increased non-Federal funding.

Figure 2-11.
Historical pattern of R&D as a percentage of GDP: 1953–98



See appendix tables 2-1 and 2-3.

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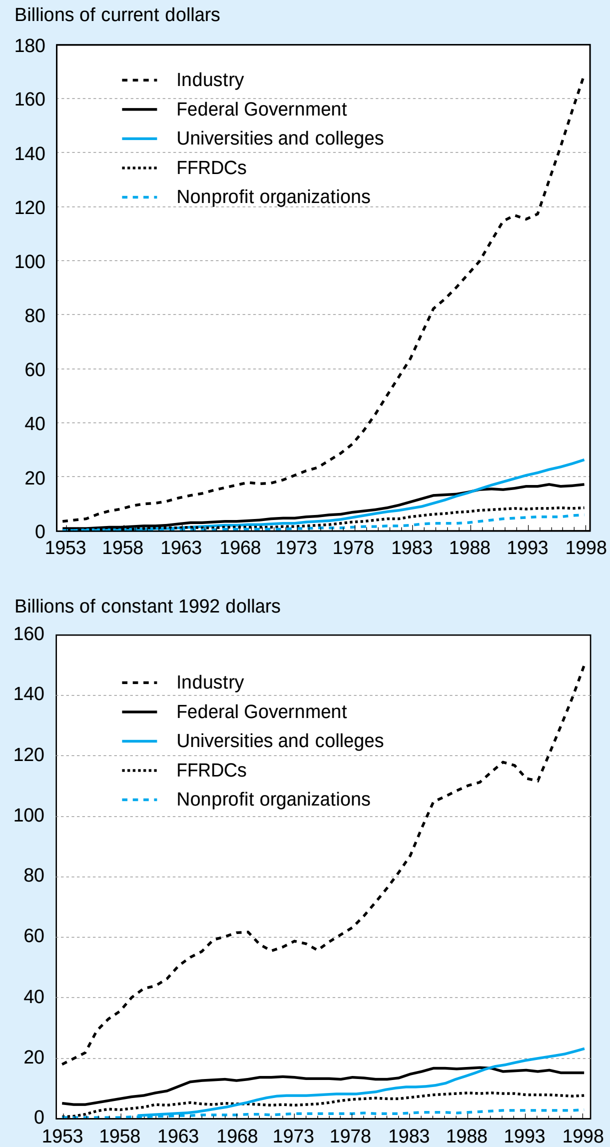
Rates of Growth Among Sectors

The sectoral shares of U.S. R&D performance, measured in terms of expenditures, have shifted significantly since the early 1980s. (See figure 2-12.) In 1980, industry—including industry-administered FFRDCs—performed 70.3 percent of the Nation's R&D, the academic sector (including academically administered FFRDCs) accounted for 13.9 percent, the Federal Government performed 12.4 percent, and the nonprofit sector (including nonprofit-administered FFRDCs) performed 3.4 percent. As industry's defense-related R&D efforts

Figure 2-12.
National R&D performance, by type of performer: 1953–1998



FFRDC = Federally Funded Research and Development Centers

See appendix tables 2-3 and 2-4.

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accelerated in the early 1980s, its share of the performance total rose to 73.4 percent in 1985.

From 1985 to 1994, R&D performance grew by only 1.1 percent per year in real terms for all sectors combined. This growth was not evenly balanced across sectors, however. R&D performance at universities and colleges (including their FFRDCs) grew by 4.1 percent per year in real terms, compared with 0.7 percent real annual growth for industry, a decline of 0.7 percent per year for Federal intramural performance, and growth of 2.9 percent per year for nonprofit organizations (including their FFRDCs).

The period from 1994 to 1998 witnessed dramatic changes in these growth rates. Total R&D performance, in real terms, averaged 5.8 percent growth per year—substantially higher than in the earlier sluggish period. Yet R&D performance at universities and colleges (including their FFRDCs) grew by only 2.5 percent per year in real terms. Industry R&D performance (including their FFRDCs) grew at a remarkable rate of 7.6 percent in real terms. (See figure 2-7.) Federal intramural performance declined by 0.6 percent per year in real terms. Nonprofit organizations (including their FFRDCs), according to current estimates, saw their R&D increase by only 2.0 percent per year in real terms over the same four-year period.

According to preliminary estimates, in 1998 academia (including FFRDCs) accounted for 14.0 percent of total U.S. R&D performance, Federal intramural activities 7.6 percent, other nonprofit organizations (including FFRDCS) 3.0 percent, and private industry (including FFRDCS) 75.4 percent. (See text table 2-1.)

Federal R&D Performance

The Federal Government, excluding FFRDCs, performed $17.2 billion of total U.S. R&D in 1998. This figure was slightly higher than the level for 1997 ($16.8 billion), which reflected only 1.2 percent growth after adjusting for inflation. Federal agencies accounted for 7.6 percent of the 1998 national R&D performance effort—continuing the gradual decline, since 1972, of Federal performance as a percentage of total R&D.

DOD has continued to perform more Federal intramural R&D than any other Federal agency; in fact, in 1998 it performed more than twice as much R&D as the next-largest R&D- performing agency, HHS (whose intramural R&D is performed primarily by NIH). (See text table 2-4.) DOD's intramural R&D performance has grown by less than 1 percent per year in real terms since FY 1980, however, reaching a level of $7.8 billion in FY 1998. Furthermore, an undetermined amount of DOD's intramural R&D ultimately appears to be contracted out to extramural performers. NASA's intramural R&D has grown by 1.7 percent per year in real terms since 1980, to $2.5 billion in FY 1998, while HHS intramural performance has grown by 3.7 percent, to $3.0 billion.[19] Together, these three agencies accounted for 77 percent of all Federal intramural R&D in FY 1998. (See text table 2-4.)

Total R&D performed by industrial, academic, and nonprofit FFRDCs combined reached $8.7 billion in 1998, which is essentially the same as its level of $8.4 billion in 1997 after adjusting for inflation. R&D at FFRDCs in 1998 represented 3.8 percent of the national R&D effort; most of this R&D ($5.5 billion in 1998) was performed by university- and college-administered FFRDCs.

Industrial R&D Performance

Recent Growth in Industrial R&D

R&D performance by private industry reached $171.3 billion in 1998, including $2.4 billion spent by FFRDCs administered by industrial firms. This total represented a 7.6 percent increase over the 1997 level of $157.5 billion—which, in turn, reflected a smaller, though still notable, real gain of 6.9 percent over 1996.

In 1998, R&D performed by industry that was not Federally financed rose 8.7 percent in real terms above its 1997 level. Overall, private companies (excluding industry-administered FFRDCs) funded 86.8 percent ($146.7 billion) of their 1998 R&D performance, with the Federal Government funding nearly all of the rest ($22.2 billion, or 13.2 percent of the total). Between 1997 and 1998, there was little or no change, in real terms, in Federal funds for these industrial R&D activities. As recently as 1987, the Federal funding share of industry's performance total (excluding FFRDCs) was 31.9 percent; however, the Federal share of industry's performance has been steadily declining since its peak of 56.7 percent in 1959. Much of that decline can be attributed to declines in Federal funding to industry for defense-related R&D activities.

R&D in Manufacturing Versus Nonmanufacturing Industries

The tendency for R&D to be performed more by large firms than small firms is greater in the manufacturing sector than in the nonmanufacturing sector. However, within each of these two sectors there is considerable variation in this regard, depending on the type of industry. Among industrial categories, those in which most of the R&D is conducted by large firms include aircraft and missiles, electrical equipment, professional and scientific instruments, transportation equipment (not including aircraft and missiles), and transportation and utilities (which is in the nonmanufacturing sector). (See text table 2-10.) In these sectors, however, much of the economic activity overall is carried out by large firms; consequently, the observation that most of the R&D in these sectors is conducted by large firms is not surprising.

Probably the most striking change in industrial R&D performance during the past two decades is the nonmanufacturing sector's increased prominence. Until the 1980s, little attention was paid to R&D conducted by nonmanufacturing companies, largely because service sector R&D activity was negligible compared to the R&D operations of companies in manufacturing industries.

[19]This increase represents the overall effect on intramural R&D for the agency, which takes into account the Social Security Administration (SSA) becoming a separate agency from HHS during fiscal year 1995. That is, the percentage increase reported would be larger, though negligibly, if HHS in 1995 had been defined as excluding SSA, as it is in 1996.

Text table 2–8.
Total (company, Federal, and other) funds for industrial R&D performance and number of R&D-performing companies in manufacturing and nonmanufacturing industries, by size of company: 1997

Distribution by size of company (Number of employees)		Funds for industrial R&D (Dollars in millions)	
Number of employees	Total	Manufacturing	Nonmanufacturing
Total	$157,539	$121,025	$36,514
Fewer than 500	24,063	8,248	15,815
500 to 999	4,966	2,905	2,061
1,000 to 4,999	19,590	14,300	5,289
5,000 to 9,999	14,266	11,670	2,596
10,000 to 24,999	21,510	16,874	4,636
25,000 or more	73,144	67,028	6,116
		Number of R&D-performing companies	
Total	35,112	18,130	16,982
Fewer than 500	31,995	15,898	16,097
500 to 999	1,127	886	241
1,000 to 4,999	1,302	938	364
5,000 to 9,999	322	197	125
10,000 to 24,999	199	138	61
25,000 or more	167	73	94

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Survey of Industrial Research and Development, 1997.*

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Prior to 1983, nonmanufacturing industries accounted for less than 5 percent of the industry R&D total. By 1993, this percentage had risen to an all-time high of 26 percent. It has fallen only slightly since then and has remained above 22 percent.[20] (See text table 2-9 and figure 2-13.)

In 1997, nonmanufacturing firms' R&D performance totaled $36.5 billion—$32.4 billion in funds provided by companies and other non-Federal sources and $4.1 billion in Federal support. (See appendix tables 2-53 and 2-54.) The large upswing in the percentage of nonmanufacturing R&D primarily reflects a sharp rise in company-supported nonmanufacturing R&D from 1987 to 1991. (See figure 2-13.) Moreover, the recent drop in this percentage in 1995–97 is attributable not to any decrease in the level of R&D from nonmanufacturing companies but to a sharp increase in company-supported R&D by manufacturing firms.

Because of recent changes in classification, little historical information exists regarding the decomposition of R&D for all nonmanufacturing firms into nonmanufacturing industrial categories. In 1997, however, the largest component of R&D for nonmanufacturing companies was R&D performed by computer and data processing services, which accounted for 8.5 percent of all industrial R&D performance. (See text table 2-9.) Wholesale and retail trade account for another 6.0 percent, and engineering and management services account for 4.4 percent. The "research, development, and testing"

Text table 2–9.
Percentage share of total company and other non-Federal funds, by selected R&D-performing industries

	1987	1997
All manufacturing industries	91.6	75.7
Industrial and other chemicals (except drugs and medicines)	8.7	5.3
Drugs and medicines	6.7	8.7
Petroleum refining and extraction	3.1	1.2
Machinery	17.2	13.8
Electrical equipment	17.0	17.0
Motor vehicles and motor vehicles equipment	11.7	10.3
Aircraft and missiles	9.7	4.2
Professional and scientific instruments	8.1	6.7
All nonmanufacturing industries	8.4	24.3
Communications services	1.7	1.4
Computer and data processing services	NA	8.5
Research, development, and testing	0.9	3.6
Wholesale and retail trade	NA	6.0
Engineering and management services	NA	4.4
Health services	NA	0.5
Finance, insurance, and real estate	NA	1.1

NA = not available

SOURCE: National Science Foundation, Division of Science Resources Studies, *Survey of Industrial Research and Development, 1997.*

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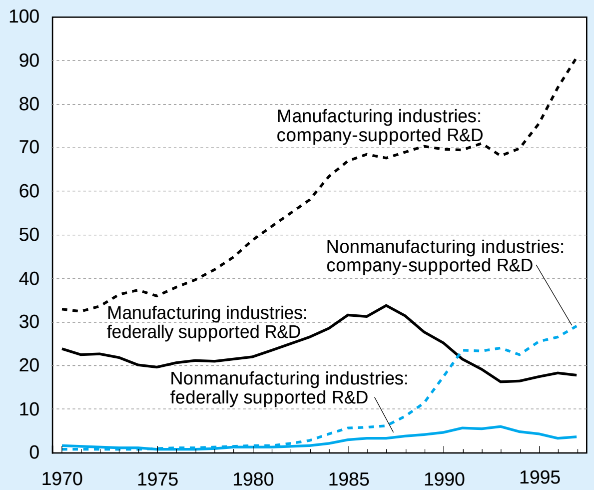
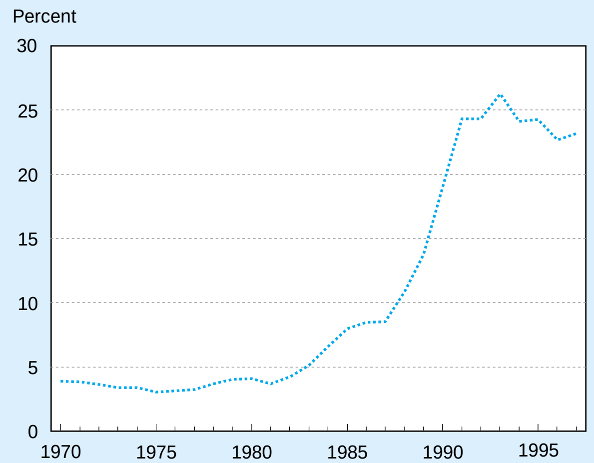
[20] As a result of a new sample design, industry R&D statistics since 1991 better reflect R&D performance among firms in the nonmanufacturing industries and small firms in all industries than they had previously. As a result of the new sample design, statistics for 1991 and later years are not directly comparable with statistics for 1990 and earlier years.

Figure 2-13.
Industrial R&D performance, by manufacturing and nonmanufacturing industries



Nonmanufacturing R&D performance as a percentage of total industrial performance



See appendix table 2-52.

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sector accounted for 3.6 percent of total industrial R&D; communications services for 1.4 percent; and finance, insurance, and real estate services for 1.1 percent.

Although a great deal of R&D in the United States is related in some way to health services, companies that are specifically categorized in the health services sector accounted for only 0.5 percent of all industrial R&D and only 2 percent of all R&D by nonmanufacturing companies. These figures illustrate that R&D data disaggregated according to standard industrial categories (including the distinction between manufacturing and nonmanufacturing industries) may not always reflect the relative proportions of R&D devoted to particular types of scientific or engineering objectives or to particular fields of science or engineering.[21] (The analysis in "R&D in Chemistry, Life Sciences, and Information Technology" compensates to some extent for this limitation in the data by providing R&D expenditure levels associated with these fields.)

On average, industrial manufacturing R&D performers are quite different from industrial nonmanufacturing R&D performers. Nonmanufacturing R&D is characterized as having many more small R&D firms than manufacturing R&D performers. (See text table 2-10.) Approximately 35,000 firms in the United States perform R&D, of which 18,000 are manufacturers and 17,000 are in the nonmanufacturing sector—nearly a 50-50 split. Yet manufacturers account for 77 percent of total industry performance (including Federally funded industry performance). The main reason for this continued dominance of the manufacturing sector is simply that among manufacturing firms, the largest (in terms of number of employees) tend to perform a relatively large amount of R&D. Among small R&D-performing firms (fewer than 500 employees) in manufacturing and nonmanufacturing sectors, those in the nonmanufacturing sector tend to conduct twice as much R&D per firm as those in the manufacturing sector. Among large R&D-performing firms (more than 25,000 employees) in both sectors, however, those in the manufacturing sector tend to conduct more than 10 times as much R&D per firm as those in the nonmanufacturing sector.

Top 20 U.S. Corporations in R&D Spending

Of the top 20 U.S. corporations in R&D expenditures in 1997 (see text table 2-11), only one—Microsoft Corporation, which had 22 thousand employees—had fewer than 25 thousand employees. The corporation that performed the most R&D in 1997 was General Motors ($8.2 billion); another company in the motor vehicle sector, Ford Motor Company, performed $6.3 billion in R&D. The next three corporations were IBM, Lucent Technologies, and Hewlett-Packard ($4.3, $3.1, and $3.1 billion in R&D, respectively). All of the top 20 corporations were associated with motor vehicle manufacturing, computers, communication equipment, or pharmaceuticals—with the exception of Procter and Gamble, which fell into the category of "other chemicals (soaps, ink, paints, fertilizers, explosives…)."[22]

[21]For a more detailed discussion of limitations in the interpretation of R&D levels by industrial categorization, see Payson (1997).

[22]These data on R&D for individual corporations were obtained from a source that is different from the NSF Survey of Industrial Research and Development—namely, from the U.S. Corporate R&D database, as provided by Shepherd and Payson (NSF 1999e). Consequently, the definition of R&D in this case is not equivalent to that in the Industry R&D Survey. In particular, the U.S. Corporate R&D database derives from R&D reported in the Standard and Poor's *Compustat* database. As such, these R&D figures include R&D conducted by these companies outside the U.S., whereas the Industry R&D Survey includes only R&D performed within the U.S. Because of this difference in the data and other differences as outlined in NSF1999e, R&D data appearing in text table 2-11 and appendix table 2-58 should not be used in conjunction with R&D data originating from NSF's Industry R&D Survey.

Text table 2–10.
Industry R&D performed by different size firms, for selected sectors: 1997
(Dollars in millions)

Industry	Sectors with more than 50 percent R&D performed by large firms (with over 25 thousand employees)	Total	Size of company in terms of the number of employees: Fewer than 500	500 to 999	1,000 to 4,999	5,000 to 9,999	10,000 to 24,999	25,000 or more
All Industries		**157,539**	**24,063**	**4,966**	**19,590**	**14,266**	**21,510**	**73,144**
Manufacturing		121,025	8,248	2,905	14,300	11,670	16,874	67,028
Aircraft and missiles	X	16,296	(D)	(D)	173	599	(D)	15,331
Drugs and medicines		11,589	234	54	2,047	2,207	3,737	3,311
Electrical equipment	X	24,585	1,789	854	3,628	3,114	1,953	13,248
Fabricated metal products		1,798	451	(D)	205	189	455	(D)
Food, kindred, and tobacco products		1,787	101	65	265	391	262	703
Lumber, wood products, and furniture		348	74	22	77	96	79	0
Office, computing, and accounting machines		12,840	830	(D)	1,375	904	2,952	(D)
Primary metals		988	47	22	146	233	(D)	(D)
Professional and scientific instruments	X	13,458	1,109	686	2,300	989	652	7,722
Stone, clay, and glass products		608	16	31	72	103	386	0
Transportation equipment (except aircraft and missiles)	X	15,697	(D)	(D)	115	247	(D)	14,537
Nonmanufacturing		36,514	15,815	2,061	5,289	2,596	4,636	6,116
Services		22,400	11,074	(D)	3,252	1,344	3,205	(D)
Transportation and utilities	X	3,013	56	22	138	70	128	2,598

D = data have been withheld to avoid disclosing operations of individual companies.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Survey of Industrial Research and Development, 1997.*

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Text table 2–11.
The 20 leading industrial R&D companies, ranked by size of R&D expenditures in 1997

Rank	Company	R&D expenditures (millions)	Sales (millions)	Number of employees	Percent change in R&D from the previous year	Industrial category
1	General Motors Corp	8,200.0	168,190	608,000	–7.87	Motor vehicles & motor vehicle equipment
2	Ford Motor Co	6,327.0	153,627	363,892	–7.24	Motor vehicles & motor vehicle equipment
3	Intl Business Machines Corp	4,307.0	78,508	269,465	9.48	Electronic computers and computer terminals
4	Lucent Technologies Inc	3,100.6	26,360	134,000	68.69	Modems & other wired telephone equipment
5	Hewlett-packard Co	3,078.0	42,895	121,900	13.25	Electronic computers and computer terminals
6	Motorola Inc	2,748.0	29,794	150,000	14.79	Radio, TV, cell phone, and satellite communication eq.
7	Intel Corp	2,347.0	25,070	63,700	29.81	Electronic components (semiconductors, coils…)
8	Johnson & Johnson	2,140.0	22,629	90,500	12.34	Drugs: pharmaceutical preparations
9	Pfizer Inc	1,928.0	12,504	49,200	14.49	Drugs: pharmaceutical preparations
10	Microsoft Corp	1,925.0	11,358	22,232	34.43	Prepackaged software
11	Boeing Co	1,924.0	45,800	238,000	60.33	Aircraft, guided missiles & space vehicles
12	Chrysler Corp	1,700.0	58,622	121,000	6.25	Motor vehicles & motor vehicle equipment
13	Merck & Co	1,683.7	23,637	53,800	13.21	Drugs: pharmaceutical preparations
14	American Home Products Corp	1,558.0	14,196	60,523	9.02	Drugs: pharmaceutical preparations
15	General Electric Co	1,480.0	88,540	276,000	4.15	Electrical equipment (industrial & household)
16	Bristol Myers Squibb	1,385.0	16,701	53,600	8.54	Drugs: pharmaceutical preparations
17	Lilly (Eli) & Co	1,382.0	8,518	31,100	16.18	Drugs: pharmaceutical preparations
18	Abbott Laboratories	1,302.4	11,883	54,487	8.10	Drugs: pharmaceutical preparations
19	Procter & Gamble Co	1,282.0	35,764	106,000	5.00	Other chemicals (soaps, ink, paints, fertilizers, explosives)
20	Pharmacia & Upjohn Inc	1,217.0	6,710	30,000	–3.87	Drugs: pharmaceutical preparations

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *U.S. Corporate R&D. Volume II. Company Information on Top 500 Firms in R&D* by C. Shepherd and S. Payson. NSF 00-302. Arlington, VA: NSF.

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R&D Intensity

In addition to absolute levels of, and changes in, R&D expenditures, another key indicator of the health of industrial science and technology is R&D intensity. R&D is similar to sales, marketing, and general management expenses in that it is a discretionary (i.e., non-direct-revenue-producing) item that can be trimmed when profits are falling. There seems to be considerable evidence, however, that R&D enjoys a high degree of immunity from belt-tightening endeavors—even when the economy is faltering—because of its crucial role in laying the foundation for future growth and prosperity. Nevertheless, whether industry devotes the right amount of economic resources to R&D has remained an open question. (See sidebar, "Does Industry Under-Invest in R&D?")

There are several ways to measure R&D intensity; the one used most frequently is the ratio of R&D funds to net sales.[23] This statistic provides a way to gauge the relative importance of R&D across industries and firms in the same industry.

The industrial sectors with the highest R&D intensities have been

- research, development, and testing services;
- computer and data processing services;
- drugs and medicines;
- office, computing, and accounting machines;

[23]Another measure of R&D intensity is the ratio of R&D to "value added" (which is sales minus the cost of materials). Value added is often used in studies of productivity analysis because it allows analysts to focus on the economic output attributable to the specific industrial sector in question, by subtracting materials produced in other sectors. For a discussion of the connection between R&D intensity and technological progress, see, for example, Nelson (1988) and Payson (in press).

Does Industry Under-Invest in R&D?

In a report published by the National Institute of Standards and Technology, Tassey (1999) suggests that private industry may be under-investing in R&D for the following reasons:

- **Technology is risky**, not only in terms of achieving a technological advance but in terms of acquiring the ability to market it first. For example, if one firm initiates the research and makes the important discoveries but another firm is able to market the new technology first, the firm that made the discovery would not recover its R&D costs. Consequently, although the economic returns to the second firm in this case would be very high—as would be the economic returns to society—the firm that initiates the effort may have good reason to be skeptical about its expected gains and may therefore be reluctant to initiate the work in the first place.
- **Spillovers from the technology** to other industries and to consumers, such as lower prices ("price spillovers") and increased general knowledge ("knowledge spillovers"), may bring many benefits to the economy as a whole, independent of the returns to the firm that performs the R&D. As Tassey notes, "To the extent that rates of return fall below the private hurdle rate, investment by potential innovators will not occur."
- **Inefficiencies result from market structures**, in which firms may face high costs of achieving comparability when they are competing against each other in the development of technological infrastructure. For example, software developers are constrained not only by the immediate development task at hand but in having to ensure that the new software they develop is compatible with software and operating systems that other firms may be developing simultaneously. Here, greater efforts undertaken by industry or government to encourage standardization of emerging technologies would likely lead to higher returns on R&D.
- **Corporate strategies**, according to Tassey, "often are narrower in scope than a new technology's market potential." In other words, companies in one line of business may not realize that the technological advances they make may have beneficial uses in other lines of business.* Thus, broader-based strategies that extend beyond a firm's immediate line of products would yield greater returns on R&D.
- **Technological infrastructure**, such as the Internet, often yields high returns to individual companies and to the overall economy but often requires substantial levels of investment before any benefits can be realized. This argument is similar to the public-goods argument that, for some large-scale R&D projects, funds from government or an organized collaboration of industry participants may be necessary for the project to achieve the "critical mass" it needs to be successful. Once a project is successful, however, high returns on R&D might be realized.

Solutions to these problems would not be simple, but NIST is addressing them. Among NIST's general goal in this regard is to encourage a "more analytically based and data-driven R&D policy" (Tassey 1999, 2).

* Levitt (1960) has referred to this kind of problem as "marketing myopia."

- optical, surgical, photographic, and other instruments;
- electronic components;
- communication equipment; and
- scientific and mechanical measuring instruments. (See text table 2-12 and appendix table 2-50.)

Among these sectors, the highest R&D intensity (38.5 percent in 1997) is observed in research, development and testing services (which is not surprising because, in this special case, R&D is the actual product sold rather than a means toward acquiring a better product or production process). Computer data and processing services are second, at 13.3 percent, followed by drugs and medicines at 10.5 percent.[24] The "office, computing, and accounting machines" sector had an R&D intensity as high as 12.3 percent in 1987, but its R&D intensity fell to 9.2 percent by 1997.

Text table 2–12.
Company and other (except Federal) industrial R&D funds as a percentage of net sales in R&D-performing companies for selected industries: 1987 and 1997

Industry and size of company	1987	1997
Manufacturing		
Drugs and medicines	8.7	10.5
Office, computing, and accounting machines.	12.3	9.2
Optical, surgical, photographic, and other instruments.	7.2	8.9
Electronic components	8.5	8.1
Communication equipment	5.5	8.0
Scientific and mechanical measuring instruments	8.1	6.5
Aircraft and missiles	3.6	3.9
Motor vehicles and motor vehicles equipment	3.4	3.8
Industrial chemicals	4.4	3.5
Other machinery, except electrical	3.0	3.0
Other electrical equipment	2.6	2.7
Radio and TV receiving equipment.	3.2	2.6
Other transportation equipment	2.5	2.2
Other chemicals	3.3	2.1
Stone, clay, and glass products	2.5	1.8
Fabricated metal products	1.2	1.5
Rubber products	1.6	1.4
Paper and allied products	0.6	1.1
Lumber, wood products, and furniture	0.6	0.9
Textiles and apparel.	0.4	0.9
Nonferrous metals and products	1.3	0.6
Petroleum refining and extraction	1.0	0.6
Ferrous metals and products	0.6	0.6
Food, kindred, and tobacco products	0.6	0.5
Nonmanufacturing		
Research, development, and testing services	5.5	38.5
Computer and data processing services	NA	13.3
Engineering, architectural, and surveying.	NA	2.6
Trade.	NA	2.4
Finance, insurance, and real estate.	NA	0.7
Telephone communications	NA	0.7
Electric, gas, and sanitary services	NA	0.1

NA = not available

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Survey of Industrial Research and Development, 1997*

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Sectors that were lowest in R&D intensity in 1997 included

- nonferrous metals and products;
- petroleum refining and extraction;
- ferrous metals and products;
- food, kindred, and tobacco products; and
- electric, gas, and sanitary services.

These sectors, in large part, reflect the "smokestack industries" that played a dominant role in the U.S. economy in the mid-1900s in terms of new directions of technological change.

Performance by Geographic Location, Character of Work, and Field of Science

R&D by Geographic Location

The latest data available on the state distribution of R&D performance are for 1997.[25] These data cover R&D performance by industry, academia, and Federal agencies, as well as Federally funded R&D activities of nonprofit institutions. The state data on R&D cover 52 records: the 50 states, the District of Columbia, and "other/unknown" (which accounts primarily for R&D for which the particular state was not known). Approximately two-thirds of the R&D that could not be associated with a particular state is R&D performed by the nonprofit sector. Consequently, the distribution of R&D by state indicates primarily where R&D is undertaken in Federal, industrial, and university facilities.

In 1997, total R&D expenditures in the United States were $211.3 billion, of which $199.1 billion could be attributed to expenditures within individual states; the remainder was "other/unknown." (See appendix table 2-20.) The statistics and discussion below refer to state R&D levels in relation to the distributed total of $199.1 billion.

R&D is concentrated in a small number of states. In 1997, California had the highest level of R&D expenditures performed within its borders ($41.7 billion, representing approximately one-fifth of U.S. total). The six states with the highest levels of R&D expenditures—California, Michigan, New York, New Jersey, Massachusetts, and Texas (in descending order)—accounted for approximately half of the entire na-

[24] R&D outlays in the semiconductor equipment and materials industry are estimated to be about 12–15 percent of sales (Council on Competitiveness 1996). The broad industry classification system used in NSF's industrial R&D survey can mask pockets of high-tech activity.

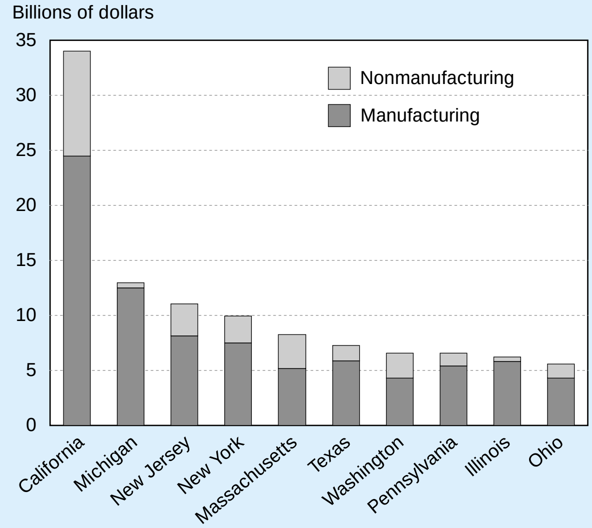
[25] Although annual data are available on the location of R&D performance by the academic and Federal sectors, until recently, NSF has conducted surveys on the state distribution of industrial R&D performance only in odd-numbered years. At this writing, the 1998 industry R&D survey data have not been processed, making 1997 the most recent year for which the state-specific R&D totals can be reported.

tional effort. The top 10 states—the six states listed above plus (in descending order) Pennsylvania, Illinois, Washington, and Maryland—accounted for approximately two-thirds of the national effort. (See appendix table 2-20.) California's R&D performance exceeded by a factor of three the next-highest state, Michigan ($14.0 billion). After Michigan, R&D levels decline relatively smoothly to approximately $7.4 billion for Maryland. The 20 highest-ranking states in R&D expenditures accounted for about 86 percent of the U.S. total; the lowest 20 states accounted for 4 percent.

States vary widely in the size of their economies owing to differences in population, land area, infrastructure, natural resources, and history. Consequently, variation in the R&D expenditure levels of states may simply reflect differences in economic size or the nature of their R&D efforts. A simple way of controlling for this "size effect" is to measure each state's R&D level as a proportion of its gross state product (GSP). (See appendix table 2-52.) As with the ratio of industrial R&D to sales, the proportion of a state's GSP devoted to R&D is referred to as R&D "intensity." Overall, the Nation's total R&D to GDP ratio in 1997 was 2.6 percent in 1997. The top 10 states with regard to R&D intensity were (in descending order) New Mexico (6.7 percent), the District of Columbia (5.3 percent), Michigan (5.1 percent), Massachusetts (5.0 percent), Maryland (4.8 percent), Washington (4.4 percent), Idaho (4.4 percent), New Jersey (4.1 percent), California (4.0 percent), and Rhode Island (3.7 percent). New Mexico's high R&D intensity is largely attributable to Federal support (provided by the Department of Energy) for the Sandia National Laboratories and Los Alamos National Laboratory FFRDCs in the state.[26]

States have always varied in terms of the levels and types of industrial operations they contain. Thus, they vary as well in the levels of R&D they contain by industrial sector. One measure of such variation among states is the extent to which their industrial R&D is in the nonmanufacturing sector as opposed to the manufacturing sector. Among the top 10 states in 1997 in industrial R&D performance, California, New Jersey, New York, Massachusetts, and Washington all had relatively high levels of R&D in the nonmanufacturing sector (25 percent or more of the total). (See figure 2-14.) Michigan, Texas, Pennsylvania, Illinois, and Ohio had lower levels of R&D in nonmanufacturing, as a percentage of the total.

Figure 2-14.
Industrial R&D performance in the top 10 states in industrial R&D in 1997: R&D in manufacturing and nonmanufacturing



NOTE: These levels include R&D performed by industry-administered FFRDCs.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Survey of Industrial Research and Development, 1997*

See appendix table 2-20. *Science & Engineering Indicators – 2000*

Trends in National R&D by Character of Work

The traditional way to analyze trends in R&D performance is to examine the amount of funds devoted to basic research, applied research, and development. (See sidebar, "Definitions.") These terms are convenient because they correspond to popular models that depict innovation occurring in a linear progression through three stages: (1) scientific breakthroughs from the performance of basic research lead to (2) applied research, which leads to (3) development or application of applied research to commercial products, processes, and services.

The simplicity of this approach makes it appealing to policymakers, even though the traditional categories of basic research, applied research, and development do not always ideally describe the complexity of the relationship between science, technology, and innovation in the real world.[27] Additionally, many analysts argue that the distinctions between basic research and applied research are becoming increasingly blurred. Nonetheless, these general categories are generally useful to characterize the relative expected time horizons and types of investments.

The United States spent $37.9 billion on the performance of basic research in 1998, $51.2 billion on applied research, and $138.1 billion on development. (See figure 2-15.) These

[26]For additional information about the geographic distribution of R&D within the United States, see NSF, "Science and Engineering State Profiles: 1999," by R. Bennof and S. Payson, forthcoming.

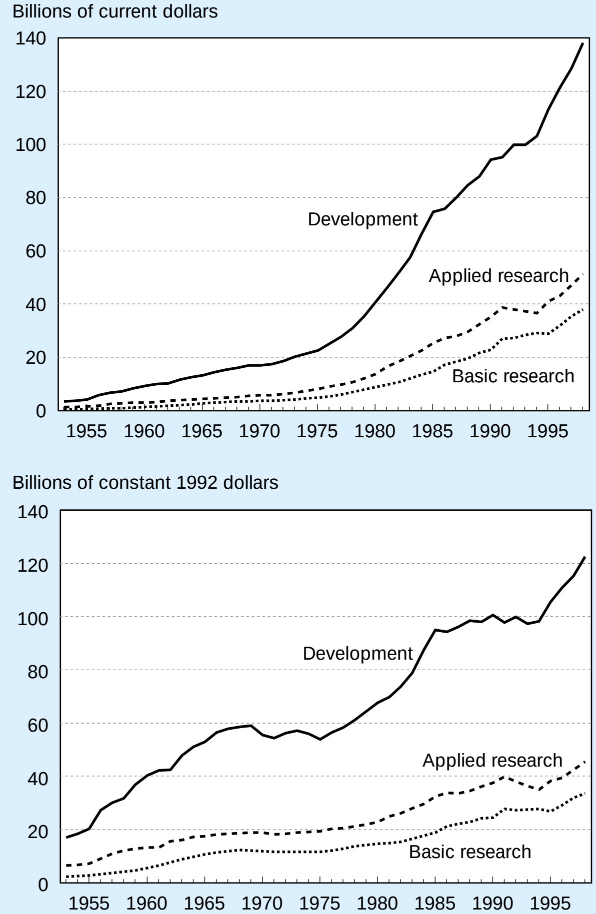
[27]See NSB (1996), chapter 4, "Alternative Models of R&D and Innovation." According to the Council on Competitiveness (1996), "The old distinction between basic and applied research has proven politically unproductive and no longer reflects the realities of the innovation process…The United States [should adopt] a new and more up-to-date vocabulary, one that accounts for changing calculations of R&D risk and relevance over short-, medium- and long-term horizons." In its report, the Council identified three types of research (short-term/low-risk, mid-term/mid-risk, and long-term/high-risk) and the economic sectors that have primary and secondary responsibility for each. In contrast, another study found that R&D managers/directors and financial officials/accountants in manufacturing and nonmanufacturing firms generally agree that NSF's classification of R&D expenditures into basic research, applied research, and development appropriately describes the scope of their companies' self-financed R&D activities (Link 1996).

Definitions

NSF uses the following definitions in its resource surveys. They have been in place for several decades and are generally consistent with international definitions.

- ♦ **Basic research**. The objective of basic research is to gain more comprehensive knowledge or understanding of the subject under study, without specific applications in mind. In industry, basic research is defined as research that advances scientific knowledge but does not have specific immediate commercial objectives, although it may be in fields of present or potential commercial interest.
- ♦ **Applied research**. Applied research is aimed at gaining the knowledge or understanding to meet a specific, recognized need. In industry, applied research includes investigations oriented to discovering new scientific knowledge that has specific commercial objectives with respect to products, processes, or services.
- ♦ **Development**. Development is the systematic use of the knowledge or understanding gained from research directed toward the production of useful materials, devices, systems, or methods, including the design and development of prototypes and processes.
- ♦ **Budget authority**. Budget authority is the authority provided by Federal law to incur financial obligations that will result in outlays.
- ♦ **Obligations**. Federal obligations represent the amounts for orders placed, contracts awarded, services received, and similar transactions during a given period, regardless of when funds were appropriated or payment required.
- ♦ **Outlays**. Federal outlays represent the amounts for checks issued and cash payments made during a given period, regardless of when funds were appropriated or obligated.
- ♦ **R&D plant**. Federal obligations for R&D plant include the acquisition of, construction of, major repairs to, or alterations in structures, works, equipment, facilities, or land for use in R&D activities at Federal or non-Federal installations.

Figure 2-15.
National R&D funding, by character of work



See appendix tables 2-7, 2-8, 2-11, 2-12, 2-15, and 2-16.

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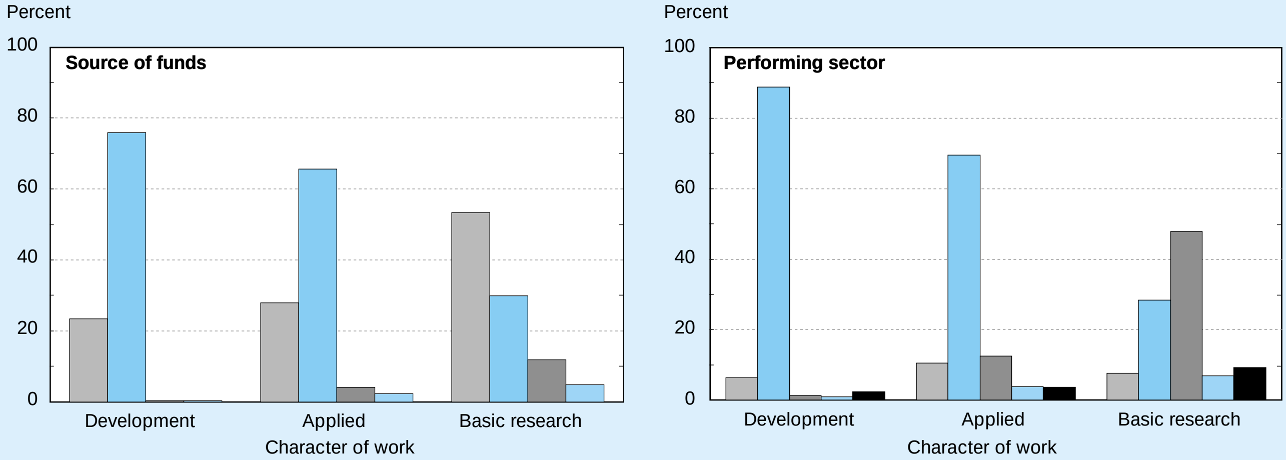
totals reflect continuous increases over several years. In particular, since 1980 there has been a 4.7 percent annual increase, in real terms, in basic research; a 3.9 percent increase in applied research; and a 3.4 percent increase in development. As a share of all 1998 R&D performance expenditures, basic research represented 16.7 percent, applied research 22.5 percent, and development 60.8 percent. These shares have not changed very much over time. For example, in 1980 basic research accounted for 13.9 percent, applied research 21.7 percent, and development 64.3 percent.

Basic Research

In 1998, basic research expenditures reached $37.9 billion. (See text table 2-1.) The annual growth rate of basic research performance has changed over time, but not as dramatically as total R&D. This annual rate, adjusted for inflation, had an average as high as 5.2 percent between 1980 and 1985; the growth rate slowed to 4.4 percent between 1985 and 1994 and increased to 5.0 between 1994 and 1998.

In terms of support, the Federal Government has always provided the majority of funds used for basic research. (See figure 2-16 and appendix table 2-9.) The Federal share of funding for basic research as a percentage of all funding, however, has dropped—from 70.5 percent in 1980 to a 53.4 percent ($20.2 billion) in 1998. (See figure 2-17.) This decline in the Federal share of basic research support does not reflect a decline in the actual amount of Federal support, which grew

Figure 2-16.
National R&D expenditures, by source of funds, performing sector, and character of work: 1998



See appendix tables 2-7, 2-9, 2-11, 2-13, 2-15, 2-16, and 2-17.

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3.1 percent per year in real terms between 1980 and 1998. Rather, it reflects a growing tendency for the funding of basic research to come from other sectors. Specifically, from 1980 to 1998, non-Federal support for basic research grew at the rate of 7.4 percent per year in real terms.

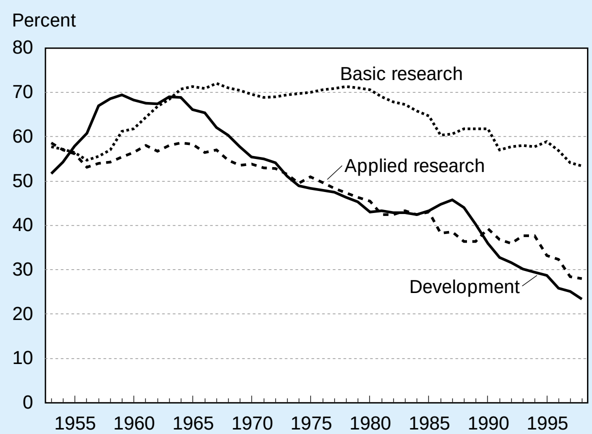
With regard to the performance of basic research in 1998, universities and colleges (excluding FFRDCs) accounted for the largest share—47.8 percent ($18.1 billion). Their performance of basic research has increased, on average, 4.6 percent annually in real terms since 1980. When the performance of university-administered FFRDCs is included, the academic sector's share climbs to 55.0 percent. In 1998, the Federal Government provided 62.1 percent of the basic research funds used by the academic sector. Non-Federal sources—including industry, state and local governments, universities and colleges themselves, and nonprofit organizations—provided the remaining 37.9 percent.

Applied Research

Applied research expenditures were $51.2 billion in 1998. Applied research is performed much more by nonacademic institutions. These expenditures have been subject to greater shifts over time, as a result of fluctuations in industrial growth and Federal policy. Applied research experienced an average annual real growth of 7.2 percent between 1980 and 1985, followed by very low growth of 0.8 percent between 1985 and 1994; the rate of growth rose again to 6.8 percent between 1994 and 1998. Increases in industrial support for applied research explains this recent upturn. Industrial support accounted for 65.6 percent ($33.6 billion) of the 1998 total for applied research; Federal support accounted for 28.0 percent ($14.3 billion).

During the 1980s, Federal support for applied research was intentionally deemphasized in favor of basic research. Even

Figure 2-17.
Federal share of total U.S. funding of basic research, applied research, and development



See appendix tables 2-9, 2-13, and 2-17.

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with the current administration's greater willingness to support generic/precompetitive applied research, Federal funding in 1998 for applied research was only 70.8 percent of that for basic research ($14.3 billion versus $20.2 billion, respectively), as reported by research performers.

With regard to performance, 69.9 percent (accounting for $35.8 billion) of the Nation's applied research was performed by industry and industry-administered FFRDCs in 1998. Federal sources funded 28.0 percent ($14.3 billion) of the Nation's applied research.

In the same year, most of the Nation's nonindustrial applied research was performed by universities and colleges and their administered FFRDCs ($7.9 billion) and the Federal Government ($5.4 billion). With regard to Federal intramural applied research, in FY 1998 23.6 percent was performed by DOD, another 23.4 percent by HHS, and 11.5 percent by NASA.[28] Total Federal applied research performance has been remarkably level for more than 30 years, experiencing only a 0.6 percent average annual growth, in real terms, since 1966.

Development

Expenditures on development in 1998 totaled $138.1 billion. Most R&D expenditures are on development. Therefore, historical patterns of development expenditures mirror historical patterns of total R&D expenditures. From 1980 to 1985, development grew on average by 7.0 percent per year in real terms as increasingly larger shares of the national R&D effort were directed toward R&D supported by DOD (which tends to be approximately 90 percent development). (See figure 2-18.) Between 1985 and 1994, on the other hand, development in real terms grew at an average annual rate of only 0.4 percent—from $74.5 billion in 1985 to $103.1 billion in 1994. Between 1994 and 1998, annual growth was back up to 5.7 percent in real terms, to $138.1 billion in 1998—of which 75.8 percent was supported by industry and 23.4 percent by the Federal Government.

In terms of performance, industry (including industrial FFRDCs) accounted for 89.9 percent ($124.1 billion) of the nation's 1998 development activities. The Federal Government accounted for 6.4 percent ($8.8 billion), and all other performers account for 3.7 percent ($5.2 billion).

[28]These percentages are derived from preliminary Federal obligations as reported in NSF (1999a).

Federal Obligations for Research, by Field

Federal Obligations for Basic Research

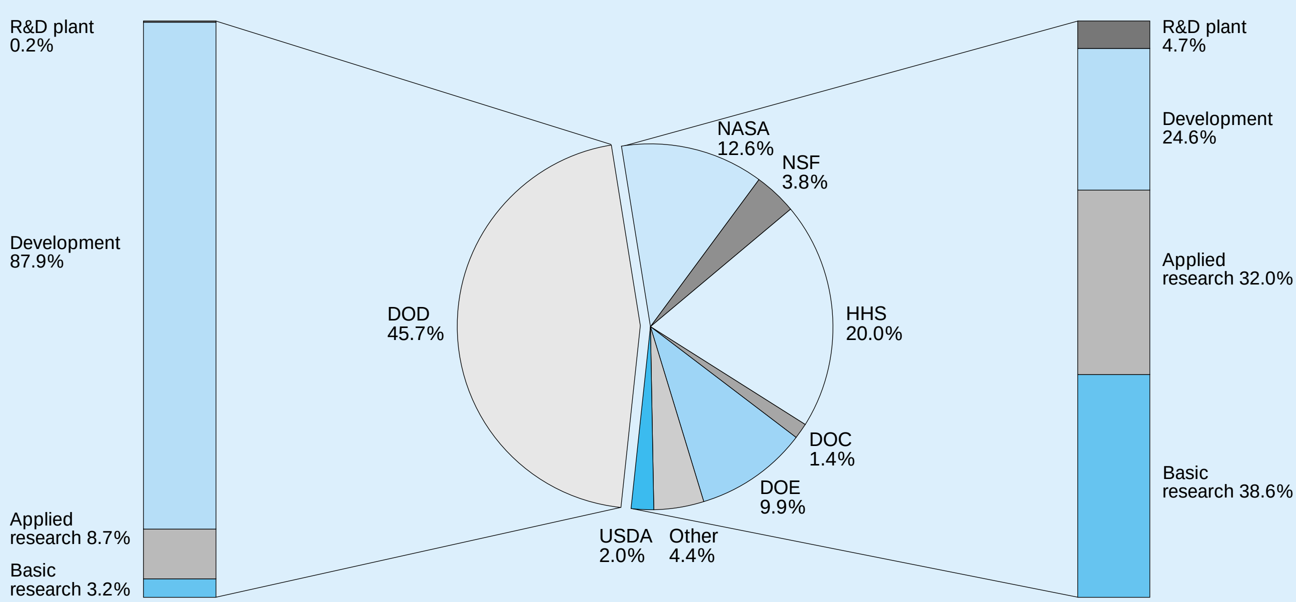
Among fields receiving Federal research support, life sciences garner the largest share of basic and applied research obligations. (See appendix table 2-47.) In FY 1999, an estimated $8.3 billion was obligated for basic research in the life sciences (which includes the biological, medical, and agricultural subfields)—nearly half the basic research total of $16.9 billion. This level of funding has grown steadily since the mid-1980s, although growth in real terms was stagnant from 1993 to 1995 (consistent with the growth pattern for all of HHS, the major funding agency for life sciences). By preliminary estimates, Federal support for basic research in the life sciences has grown rapidly between FY 1997 and FY 1999(averaging 6.2 percent per year in real terms. (See figure 2-20 and appendix table 2-47.)

DOE is the largest provider of funding for basic research in the physical sciences. According to preliminary estimates, DOE provided $1,358 million of a total of $3,305 million in FY 1999; NASA provided $972 million, and NSF provided $551 million (devoted to a wide variety of fields). Federal support for basic research in the physical sciences grew in real terms from 1985 to 1991, then declined from 1991 to 1996, and has since been rising again. (See figure 2-20.)

Federal Obligations for Applied Research

Life sciences received the largest Federal support for applied research: an estimated $6.1 billion in FY 1999 (38 percent of the $16.1 billion total). Engineering received the next largest share, with $4.3 billion in obligations (27 percent of

Figure 2-18.
Projected Federal obligations, by agency and character of work: 1999



See appendix tables 2-27, 2-29, 2-31, and 2-33.

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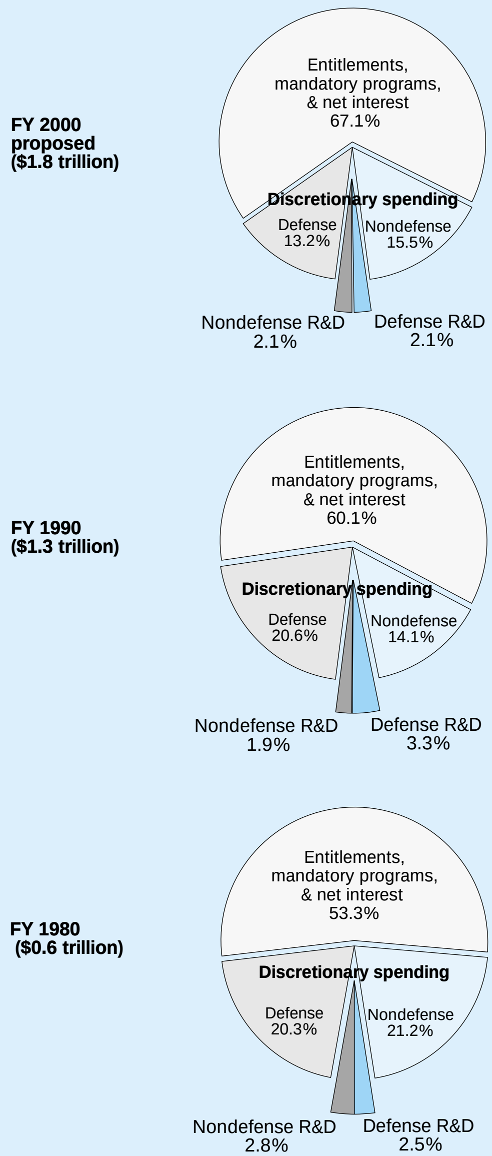
R&D Continues to Fare Well Despite Fiscal Austerity

Reducing the deficit has been an overriding goal of Congress and the Clinton Administration. To gain a better understanding of the difficulty involved in accomplishing this objective, it is helpful to split total Federal spending into two categories—"mandatory" and "discretionary." Certain program expenditures—including those for Social Security, veterans' benefits, Medicare, Medicaid, and interest on the national debt—are considered mandatory items in the Federal budget. That is, the government is already committed by law to finance those programs at certain levels and cannot cut them without a change in the law through an act of Congress. In contrast, discretionary items, including R&D programs, do not enjoy the same level of protection from budget-cutting proposals; the Federal Government does not have to, or is not already committed by law to, finance such programs at particular levels.

In FY 2000, mandatory programs (including interest on the national debt) are expected to account for 67 percent of total Federal outlays. (See appendix table 2-22.) Despite the vulnerability of R&D as a component of discretionary spending, Federal support for R&D has received bipartisan support and has fared well during the fiscal austerity of the past two decades. (See figure 2-19.) For example, an examination of R&D as a percentage of the total Federal budget reveals the following:

- Although all Federally funded R&D is expected to fall from 5.2 percent of the budget in 1990 to 4.3 percent in 2000, nondefense R&D as a percentage of the total budget is expected to rise slightly—from 1.9 percent in 1990 to 2.1 percent in 2000.
- As a proportion of total discretionary outlays, R&D increased from 11.5 percent in 1980 to 13.1 percent in 1990 and is expected to be 13.0 percent in 2000.
- Nondefense R&D as a percentage of nondefense discretionary spending has been holding fairly steady since 1980, at just less than 13 percent.

Figure 2-19.
R&D share of the Federal budget

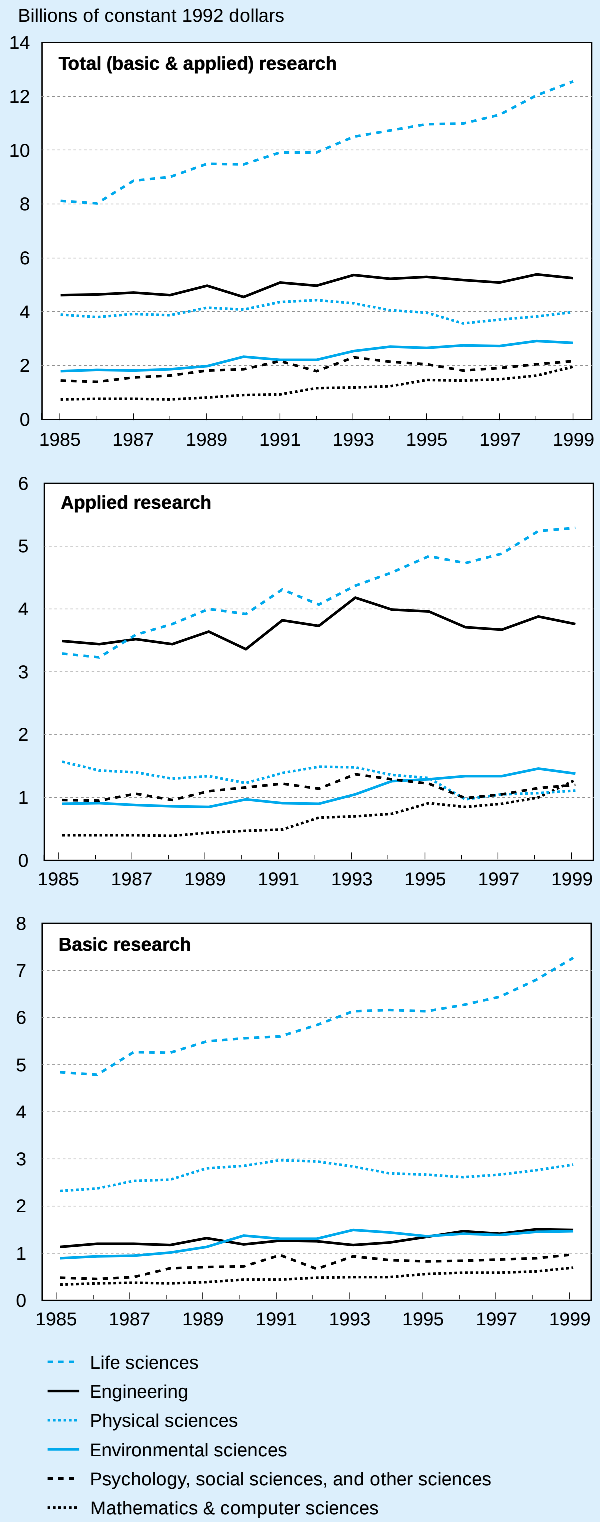


SOURCE: AAAS, *Research and Development: FY 2000*.

See appendix table 2-22. *Science & Engineering Indicators – 2000*

the total). In real terms, Federal support for applied research in the life sciences has grown substantially between 1985 and 1999 (from $3.3 billion to $5.3 billion in constant 1992 dollars. Federal support for applied research in mathematics and computer sciences has experienced particularly strong growth over the same period, from $402 million to nearly $1.3 billion in 1992 dollars. In contrast, Federal support for applied research in engineering, psychology, social sciences, and other sciences has grown very little or decreased slightly in real terms over the same period. Environmental sciences showed moderate growth between 1985 and 1999, from $898 million to nearly $1.4 billion in 1992 dollars. Federal support for applied research in the physical sciences, however, showed a decline in real terms—from $1.6 billion to $1.1 billion in 1992 dollars. On the other hand, Federal support for the physical sciences had been rising since its low of $966 million (in constant 1992 dollars) in 1966.

Figure 2-20.
Federal obligations for research by field: basic research, applied research, and total research



See appendix tables 2-47 and 2-48.

Science & Engineering Indicators – 2000

Federal Obligations for Research (Basic and Applied)

Considering basic and applied research together, the growth of Federal support for research the life sciences vis-a-vis research in other fields is even more pronounced. (See figure 2-20.) In terms of rates of growth, Federal support for research in mathematics and computer sciences has grown rapidly as well.[29]

Cross-Sector Field-of-Science Classification Analysis

A challenging, open-ended—yet promising—method of classifying R&D expenditures, in various sectors in addition to academia, is by field of science. Such classification, applied to historical data, indicates how R&D efforts in various fields of science and engineering have grown in economic importance over time. This information is potentially useful for science policy analysis and for planning and priority-setting. Moreover, scientists and engineers themselves can benefit from information about how R&D expenditures in various fields of science and engineering have evolved over time. For example, such information might influence decisions by scientists and engineers—and science and engineering students—about taking on new research endeavors or exploring new career opportunities.

Classification of academic R&D by field of science is provided in detail in chapter 6 of this report. The only additional sector for which extensive data by field exist is the Federal Government. Industrial R&D—which represents three-quarters of all R&D performed in the United States—has not been subdivided by field of study, for three reasons: (1) Unlike research performed by universities and Federal agencies, much of the research by private firms is confidential (for obvious reasons), and the provision of such information might compromise that confidentiality; (2) most private companies do not have the accounting infrastructure in place to compile such statistics, so any efforts on their part to provide this additional information could be significantly burdensome to them; and (3) much of the R&D carried out by industry is interdisciplinary, especially at the development stage (e.g., the development of a new vehicle would involve mechanical engineering, electrical engineering, and other fields)—which in many cases might make the splitting of R&D by field somewhat arbitrary. Therefore, the collection of such data is unlikely.

Nonetheless, some analysis along these lines, wherever possible, could shed light on overall levels of R&D support for general lines of inquiry. The analysis that follows circumvents this problem by grouping fields with standard industrial categories, creating nine general categories of R&D that can be associated with fields of science and engineering and with related industrial categories.

[29]For much more detailed data on Federal support by field of science, see Board on Science, Technology, and Economic Policy (1999).

R&D in Chemistry, Life Sciences, and Information Technology

In this section, R&D is categorized into three broad areas; each area is associated with academic fields of study and with industrial end-products that tend to be associated with those fields. For easier data interpretation, all academic and Federal fiscal year data were converted to calendar year data so they would be comparable to data pertaining to industry categories (which are collected and provided on a calendar year basis). Furthermore, all dollar amounts in this section are in real (constant 1992) terms, thereby allowing the analysis to focus on effects that are independent of inflation.

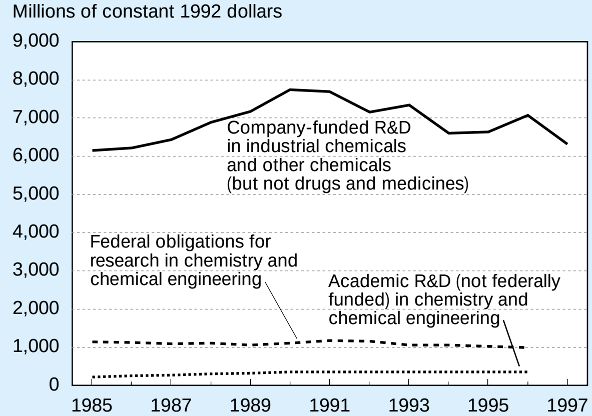
Chemistry (Nonmedical) and Chemical Engineering

Three categories of R&D were identified that could be associated primarily with chemistry and chemical engineering. (See figure 2-21 and appendix table 2-49.) These categories exclude chemistry associated with medicine, which was included instead under the broad category of life sciences. The largest of these categories, by far, is company-funded R&D in industrial chemicals and other chemicals (but not drugs and medicines). In real terms, expenditures in this category grew from $6.1 billion in 1985 to $7.7 billion in 1990 and then eventually declined, on average, to $6.3 billion in 1997—only slightly higher than the level 12 years earlier. The next two categories were much smaller. Federal obligations for research in chemistry and chemical engineering remained at roughly $1 billion (in constant 1992 dollars) throughout the 1985–96 period. The smallest category—academic R&D (not Federally funded) in chemistry and chemical engineering—grew steadily in real terms, from $223 million in 1985 to $361 million in 1996.

Life Sciences

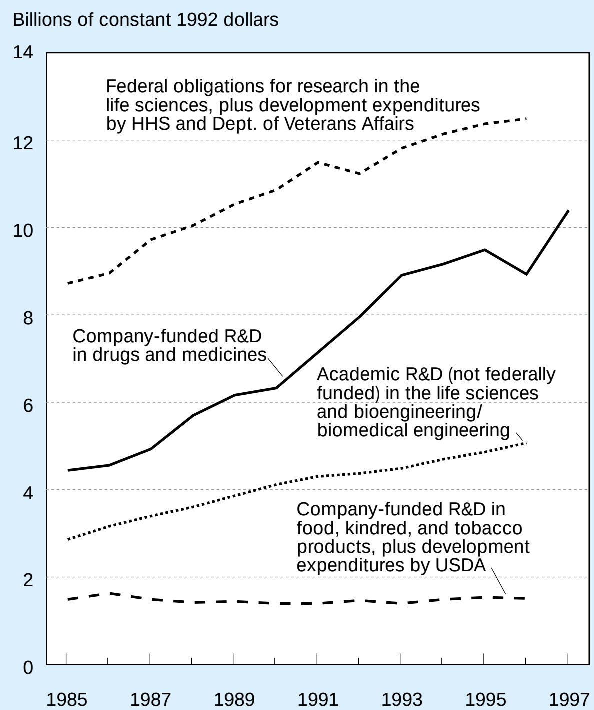
R&D in the broad area of the life sciences is characterized by strong and fairly-continuous real growth in its three largest categories. (See figure 2-22 and appendix table 2-50.) The largest category, Federal obligations for research in the life sciences, increased from $8 billion in 1985 to $11 billion in 1996. Company-funded R&D in drugs and medicines grew dramatically in real terms, from $4 billion in 1985 to $10 billion in 1997. Likewise, academic R&D (not Federally funded) in the life sciences and bioengineering/biomedical engineering grew continuously, from $3 billion in 1985 to $5 billion in 1996. Real growth in R&D also occurred in development expenditures by HHS and the Department of Veterans Affairs. With regard to food and other agricultural products that are also associated with life sciences, real growth occurred in the relatively small levels of development expenditures by USDA (from $41 million to $77 million between 1985 and 1996), but very little real change occurred in company-funded R&D in food, kindred, and tobacco products (which grew from $1.4 billion to $1.6 billion between 1985 and 1997).

Figure 2-21.
R&D associated primarily with chemistry (nonmedical) and chemical engineering



See appendix table 2-49. *Science & Engineering Indicators – 2000*

Figure 2-22.
R&D associated primarily with the life sciences

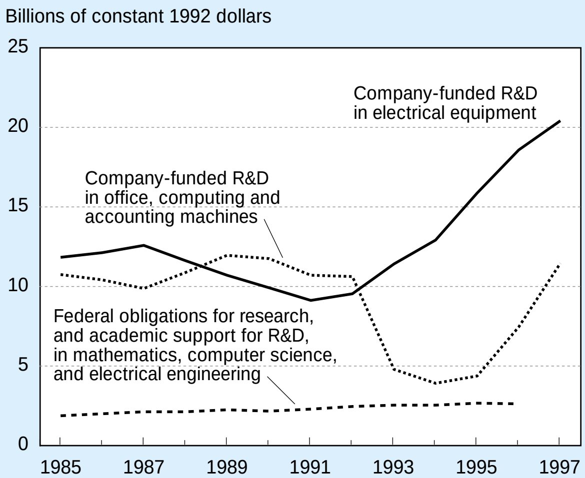


See appendix table 2-50. *Science & Engineering Indicators – 2000*

Mathematics, Computer Science, and Communication and Electrical Equipment

Although seven categories of R&D fall under this broad area, two clearly dominate the others in terms of the magnitude of their expenditure levels. (See figure 2-23 and appendix table 2-51.) The largest area, by 1997, was company-funded R&D in electrical equipment, which held steady at

Figure 2-23.
R&D associated primarily with mathematics, computer science, and communication and electrical equipment (excluding DOD-supported development of military equipment)



See appendix table 2-51. *Science & Engineering Indicators – 2000*

close to $10 billion (in constant 1992 dollars) throughout 1985–92, after which it doubled to more than $20 billion by 1997. The second-largest category in 1997—company-funded R&D in office, computing and accounting machines—remained at or above $10 billion between 1985 and 1992 as well. It then fell sharply in 1993 to below $5 billion but recovered between 1995 and 1997; by 1997 it represented more than $11 billion in R&D. The third-largest category, Federal obligations for research in mathematics and computer science, grew from $745 million in 1985 to nearly $1.5 billion in 1996. Federal obligations for research in electrical engineering (not Federally funded) declined from $813 million to $601 million over the same period. Three small academic categories—R&D in mathematics, computer science, and electrical engineering—each nearly doubled in real terms between 1985 and 1996.

Inter-Sector and Intra-Sector Domestic Partnerships and Alliances

In the performance of R&D, organizations can collaborate, either within the same sector (e.g., a partnership between firms) or between sectors (e.g., a partnership between a firm and the Federal Government). Decisions by organizations to form these partnerships are based on economic considerations, legal and cultural frameworks, scientific and technological conditions, and policy environments.

Economic Considerations Underlying R&D Partnerships

Collaboration allows individual partners to leverage their resources, reducing costs and risks and enabling research ventures that might not have been undertaken otherwise. In the case of intra-sector collaboration, the underlying theme is that more can be accomplished at lower cost when resources are pooled, especially if organizations can complement each other in terms of expertise and/or research facilities. For private companies, another advantage of partnerships is that they reduce (or eliminate) competition between the allied companies, which may thereby enjoy higher profits once their jointly developed product is marketed.

With regard to university-industry alliances, companies can benefit from the extensive research infrastructure (including the students), as well as the store of basic scientific knowledge, that exists at universities—which those firms would not be able afford on their own.[30] Universities, on the other hand, benefit from alliances with firms by being better able to channel academic research toward practical applications" (Jankowski 1999).

In the case of collaboration between Federal laboratories and industry—in the form of Cooperative Research and Development Agreements (CRADAs)—a wide range of economic benefits to both parties have been noted. The main reason for the creation of CRADAs was that industry would benefit from increased access to government scientists, research facilities, and the technology they developed. Government, in turn, would benefit from a reduction in the costs of items it needs to carry out its objectives (Lesko and Irish 1995, 67). Both would benefit from technology transfer, and Federal R&D in national labs would be more useful to U.S. industry. Some analysts have argued as well that Congress created CRADAs[31] to simplify negotiations between the Federal Government and industry in the process of technology transfer, by making the process exempt from Federal Acquisition Regulation (FAR) requirements.

With regard to collaboration between academia and the Federal Government, little exists in the strict sense of employees from both working together, side-by-side, on R&D projects. On the other hand, collaboration in a broad sense is quite extensive in that academia receives research grants to perform "targeted research."[32] (See "Federal Support to Academia.") Some of this research is designed to meet Fed-

[30]On the topic of firms benefiting from the tacit knowledge of universities, Prabhu (1997)—citing earlier work by Tyler and Steensma (1995)—suggests, "The greater the tacitness of technology (hard to document in writing, residing in individuals, systems and processes of the firm, and difficult to transfer through market mechanisms), and the greater the complexity of technology (variety and diversity of technologies that must be incorporated into the development process), the more likely it is that executives will consider technological collaboration a mode of technology development."

[31]See the next section on the legal reasons for partnerships and alliances.

[32]Targeted research as a policy goal is discussed in U.S. Congress, House Committee on Science (1998).

eral needs, in cases in which the Federal Government does not have the physical or human resources to perform the research itself. In other cases, the Federal Government may support academic research (or research in other sectors) for the sake of creating a "public good" that would be expected to provide economic benefits to society. As many people know, one of the public goods that arose from this kind of collaborative effort is the Internet, which originated from a project funded by the Defense Advanced Research Projects Agency (DARPA) and then greatly advanced through NSF funding to universities.

Finally, international competition adds two additional considerations. First, Federal-industry partnerships and other types of partnerships in the performance of R&D in the United States may be desirable as a means of competing adequately against similar partnerships carried out in other nations. Second, the United States may choose to enter into international projects with the idea that, just like firms, nations may be able to pool resources that collectively enhance their R&D capabilities.

Federal Technology Transfer Programs

The term "technology transfer" can cover a wide spectrum of activities, from informal exchanges of ideas between visiting researchers to contractually structured research collaboration involving the joint use of facilities and equipment. Only since the late 1980s, however, has technology transfer become an important mission component of most Federal labs. Some agencies, however, have long shared their research with the private sector (e.g., USDA's Agricultural Research Experiment Stations and NASA's civilian aeronautics programs), and several laws passed in the early 1980s encouraged such sharing—notably, the Stevenson-Wydler Technology Innovation Act of 1980. (See sidebar, "Principal Federal Legislation Related to Cooperative Technology Programs.")

The emphasis, in the past decade, on technology transfer stems from practical considerations: Industry was interested in such programs, Federal money was available, and government defense labs were amenable to such activities as an alternative to their declining defense work (OTA 1995). Moreover, technology transfer was regarded as a means of addressing Federal concerns about U.S. industrial strength and world competitiveness. Another reason was that the Federal Technology Transfer Act (FTTA) of 1986 authorized government-owned and -operated laboratories to enter into CRADAs with private industry. Only after the 1989 passage of the National Competitiveness Technology Transfer Act (NCTTA), however, could contractor-operated labs (including DOE's FFRDCs) also enter into CRADAs. According to most available indicators, Federal efforts to facilitate private-sector commercialization of Federal technology have made considerable progress since 1987.

Four measures of the extent of Federal technology commercialization efforts and Federal-industry collaboration between 1987 and 1998 can be described as follows:

Principal Federal Legislation Related to Cooperative Technology Programs

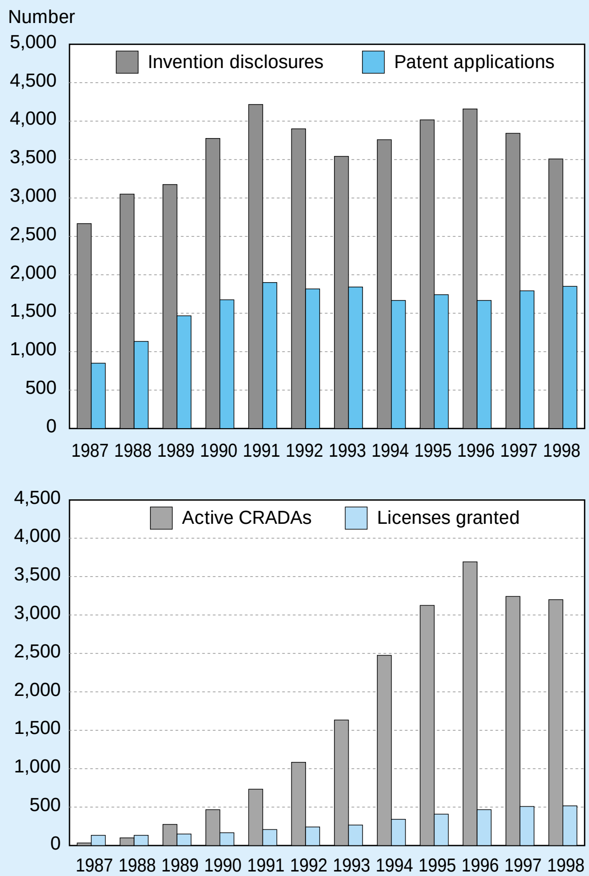
Since 1980, a series of laws have been enacted to promote Federal–civilian partnerships and to facilitate the transfer of technology between sectors. Among the most notable pieces of legislation have been the following:

- **Stevenson-Wydler Technology Innovation Act (1980).** Required Federal laboratories to facilitate the transfer of Federally owned and originated technology to state and local governments and to the private sector.
- **Bayh-Dole University and Small Business Patent Act (1980).** Permitted government grantees and contractors to retain title to Federally funded inventions and encouraged universities to license inventions to industry. The Act is designed to foster interactions between academia and the business community.
- **Small Business Innovation Development Act (1982).** Established the Small Business Innovation Research (SBIR) Program within the major Federal R&D agencies to increase government funding of research with commercialization potential within small, high-technology companies.
- **National Cooperative Research Act (1984).** Encouraged U.S. firms to collaborate on generic, precompetitive research by establishing a rule of reason for evaluating the antitrust implications of research joint ventures. The Act was amended in 1993 by the National Cooperative Research and Production Act, which let companies collaborate on production as well as research activities.
- **Federal Technology Transfer Act (1986)**. Amended the Stevenson-Wydler Technology Innovation Act to authorize CRADAs between Federal laboratories and other entities, including state agencies.
- **Omnibus Trade and Competitiveness Act (1988).** Established the Competitiveness Policy Council to develop recommendations for national strategies and specific policies to enhance industrial competitiveness. The Act created the Advanced Technology Program and the Manufacturing Technology Centers within NIST to help U.S. companies become more competitive.
- **National Competitiveness Technology Transfer Act (1989)**. Amended the Stevenson-Wydler Act to allow government-owned, contractor-operated laboratories to enter into cooperative R&D agreements.
- **National Cooperative Research and Production Act (1993)**. Relaxed restrictions on cooperative production activities, enabling research joint venture (RJV) participants to work together in the application of technologies they jointly acquire.

- **CRADAs** grew in number geometrically, from 34 in 1987 to 3,688 in 1996—an average growth rate of more than 68 percent per year. Between 1996 and 1997, however, not only did the growth cease, the number of active CRADAs declined to 3,239. This number decreased slightly in 1998, to 3,201. (See figure 2-24.)

- **Invention disclosures** arising out of CRADAs increased rapidly at first, from 2,662 in 1987 to 4,213 in 1991(a 58 percent increase in only four years). Over the succeeding seven years (to 1998), however, that level was not reached again; the largest number was 4,153 in 1996. On the other hand, there is no apparent trend in the annual numbers of invention disclosures since 1991; those levels seem to be random, averaging 3,815 and remaining above 3,500 each year. (See figure 2-24.)

Figure 2-24.
Federal technology transfer indicators



CRADA = cooperative research and development agreement.

NOTE: Does not include CRADAs entered into by NASA.

See appendix table 2-60. *Science & Engineering Indicators – 2000*

- **Patent applications** have had a similar history. They rose in number from 848 in 1987 to a high of precisely 1,900 in 1991(a 124 percent increase). After 1991, patent applications averaged 1,765, with no apparent trend.

- **Licenses** granted rose in number steadily between 1987 and 1998, from 128 to 510.

Differences in Motivations and Goals of CRADA Participants

Studies have indicated that although partnerships between sectors offer economic and scientific benefits to the parties involved, those partnerships may be constrained by cultural differences between sectors. Some observers have argued that industrial scientists and engineers tend to place much greater emphasis than their government colleagues on profitability, international competitiveness, and turnaround time. Conversely, government scientists and engineers tend to have longer-range and more idealistic perspectives. For example, Lesko and Irish (1995) describe the Federal defense employee's "traditional view" as one in which "the primary mission…is to develop, produce, enhance, and support the military systems that provide a warfighting capability for the U.S. that is second to none" (Lesko and Irish 1995, 33–34).

Rogers et al. (1998) surveyed participants in CRADA partnerships at Los Alamos National Laboratory. They found that, according to private companies in these partnerships, the top five objectives of CRADAs were (in descending order of importance) to obtain new technology/information/patents, to save money in developing a process/product, to save costs, to improve research ability within the company, and to obtain a new product. In contrast, the top five objectives according to Federal R&D laboratory partners were to improve the research ability of the Federal R&D laboratory, such as adding capabilities; to obtain new funding; to obtain technology/information/patents; to gain credibility/prestige/employee satisfaction; and to develop or gain access to new facilities/tools. According to Rogers et al., such differences in orientation have been a major obstacle to further increases in the number of CRADAs. Rogers et al. conclude, "Since 1994, Federal funding for establishing new CRADAs has almost disappeared, mainly due to partisan differences about the role of the Federal Government in its relations with private companies" (Rogers et al. 1998, 87).

On the other hand, Lesko and Irish (1995) are more optimistic about the future ability of scientists and engineers from these different cultures to get along:

> Significant differences in the perspectives of government and industry can and do impede progress in cooperative ventures. As both sides realize that they need each other's perspectives and combined resources to survive global competition and effectively manage shrinking resources, their goals and procedures will change toward becoming more and more cooperative. Good communications can be a key to identifying, understanding, and overcoming culturally derived barriers to this process (Lesko and Irish 1995, 29).

Scientific and Technological Conditions Underlying R&D Partnerships

The complexity and interdisciplinary nature of R&D has continued to increase in recent years, as discoveries in one area of science or engineering (e.g., modular robotics systems) have had bearing on other areas (e.g., space exploration). As the scope of R&D on any topic expands, researchers from individual institutions may find themselves less able to approach the topic as broadly as they think they should; they may therefore search for collaborators who can complement their knowledge or research facilities. For example, academic researchers increasingly have sought to leverage resources and talents in the conduct of R&D. Not only does such an approach offer opportunities for alternative funding, such partnership provides an essential means for undertaking work that is becoming ever more complex and multidisciplinary (Jankowski 1999).

At the same time that scientific and engineering developments are increasing the need for—and the benefits of—R&D partnerships and alliances, advances in communication equipment and software are creating new tools that make such collaborative efforts much easier. Hazlett and Carayannis (1998) describe recent developments in "virtual teams"—especially between industry and academia—whereby communication, data acquisition, data sharing, and document sharing can all take place virtually among individuals in distant organizations. In effect, the operational costs of collaborating have been reduced enormously, thereby encouraging increased collaboration among researchers of the same or similar topics.

Current research on expanding Internet capabilities offers even more powerful tools for collaborative efforts. DOE and NSF have been sponsoring research that has been moving scientists and engineers closer to having the ability to collaborate in virtual laboratories or conference rooms through "telepresence." That is, researchers at remote physical locations interact with one another in a virtual, three-dimensional environment, experiencing each other's artificial presence as though everyone were in the same room. Such capabilities will undoubtedly enhance collaboration potential.[33]

Industrial R&D Consortia

In the early 1980s, increasing international competition and the resulting erosion in U.S. technological leadership led legislators and policymakers to conclude that existing U.S. antitrust laws and penalties were too restrictive and could be impeding the ability of U.S. companies to compete in the global marketplace. U.S. companies were at a disadvantage relative to their foreign counterparts because an outdated antitrust environment—designed to preserve domestic competition—prohibited them from collaborating on most activities, including R&D.

Restrictions on multi-firm cooperative research relationships were lifted with the passage of NCRA in 1984. This law was enacted to encourage U.S. firms to collaborate on generic, precompetitive research. To gain protection from antitrust litigation, NCRA requires firms engaging in RJVs to register them with DOJ.[34] In 1993, Congress again relaxed restrictions—this time on cooperative production activities—by passing the National Cooperative Research and Production Act, which enables participants to work together to apply technologies developed by their RJVs.

The advantages of RJVs over individual firms conducting R&D on their own have been identified as follows:[35]

- Through RJVs, companies have "the ability to pool research resources in order to achieve a critical minimum mass and pursue more and larger research projects than any single company could afford."
- RJVs can exploit synergies from the complementary research strengths of their members, creating a whole greater than the sum of its parts.
- RJVs are expected to be in a better position than any single firm to maintain the necessary continuity of effort for long-term research projects.
- RJVs pool risk both in terms of a larger number of participants in each research project and a larger number of projects.
- RJVs can reduce duplication of effort among member firms by concentrating larger resources on projects of common interest.
- RJVs can attract supplemental support from external sources, including the government, by increasing the visibility of essential industrial research projects.
- RJVs can create new investment options in technologies that are out of the reach of individual member firms because of high resource commitment required, high uncertainty, insufficient appropriability of the research outcome, inadequacy of existing capabilities, and so forth.

By the end of 1998, 741 RJVs had been registered; organizations such as Sematech have helped U.S. industries regain leadership in global markets for high-tech products such as semiconductors. On the other hand, by 1998 the number of new RJV filings per year had fallen sharply to 31, after reaching a peak of 115 in 1995 (Link 1999). (See figure 2-25.)

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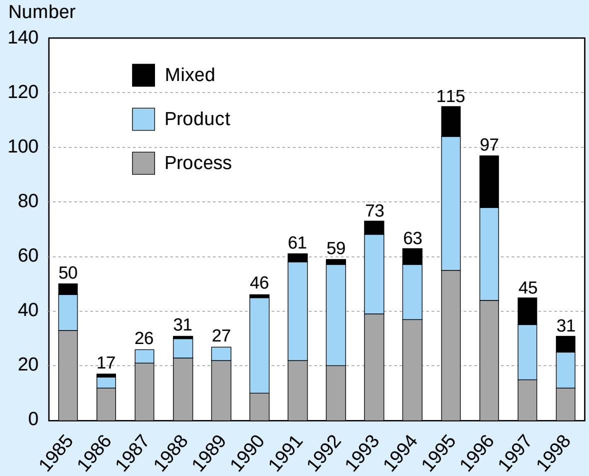
[33]See Smith and Van Rosendale (1998), Larson (1998), and chapter 9 of this report.

[34]According to NCRA, an RJV is "any group of activities, including attempting to make, making, or performing a contract, by two or more persons for the purpose of (a) theoretical analysis, experimentation, or systematic study of phenomena or observable facts, (b) the development or testing of basic engineering techniques, (c) the extension of investigative findings or theory of a scientific or technical nature into practical application for experimental and demonstration purposes… (d) the collection, exchange, and analysis of research information, or (e) any combination of the [above]." RJV members can be from different sectors as well as from different countries.

[35]These points are taken from Vonortas (1997); however, Vonortas credits these ideas to Douglas (1990).

Figure 2-25.
Growth in R&D consortia registered under the National Cooperative Research and Production Act



SOURCE: Link (1999) and unpublished tabulations.

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Other observations include:

- The industry with the most RJVs over the 1985–98 period was communication services (standard industrial classification, or "SIC," number 48), which claimed 131 of the 741 total. The electronics industry (SIC 36) was a close second with 120, followed by transportation equipment (SIC 37) with 115.
- The average number of members per RJV over the 1985–98 period was 13; this number varied by industry, however, from an average of only 6 members for the communications services industry to an average of 25 for the electronics industry.
- Only 10 percent of all RJVs included Federal laboratories as research members. Among RJVs in the communications services industries, less than 1 percent had Federal labs as members. Among those in machinery and computer equipment (SIC 35), 21 percent included Federal labs; among those in electronics, 20 percent included Federal labs.
- Sixteen percent of all RJVs included universities as research members. For communications services, this percentage was as low as 5, whereas for electronics it was as high as 34.
- As many as 29 percent of all RJVs had foreign affiliates as research members, ranging from 17 percent for transportation equipment to 45 percent for the oil and gas extraction industry (SIC 13).
- Fourteen percent of RJVs had an environmental research focus; no RJVs in communications services had an environmental research focus, whereas 43 percent in chemicals and allied products (SIC 28) had that focus.
- Forty-nine percent of RJVs (365 of the 741 total) had research that was process-focused; 41 percent (307) had research that was product-focused; and the remaining 9 percent (69) had research that included both. (See figure 2-25.)

International Comparisons of National R&D Trends

Absolute levels of R&D expenditures are indicators of the breadth and scope of a nation's S&T activities and are a harbinger of future growth and productivity. Indeed, investments in the R&D enterprise strengthen the technological base on which economic prosperity increasingly depends worldwide. Findings from a study of 25 countries by Porter and Stern (1999) indicate that human talent and R&D spending are among the most important factors contributing to nations' innovative capacity. Consequently, the relative strength of a particular country's current and future economy—and the specific scientific and technological areas in which a country excels—is further revealed through comparison with other major R&D-performing countries. This section provides such comparisons of international R&D spending patterns.[36] It examines absolute and relative expenditure trends, contrasts performer and source structural patterns, reviews the foci of R&D activities, and looks at government priorities and policies. Although R&D performance patterns by sector are similar across countries, national sources of support differ considerably. In nearly all OECD countries, government has provided a declining share of all R&D funding during the past decade, whereas the industrial share of the funding total has increased considerably. Foreign sources of R&D have been increasing in many countries.

Absolute Levels of Total R&D Expenditures

The worldwide distribution of R&D performance is concentrated in relatively few industrialized nations. Of the $500 billion in estimated 1997 R&D expenditures for the 28 OECD[37] countries, 85 percent is expended in just 7 countries (OECD 1999d). These estimates are based on reported R&D investments (for defense and civilian projects) converted to U.S. dollars with purchasing power parity (PPP) exchange rates.[38] (See appendix table 2-2.)

[36]Most of the R&D data presented here are from reports to OECD, which is the most reliable source of such international comparisons. A fairly high degree of consistency characterizes the R&D data reported by OECD, with differences in reporting practices among countries affecting their R&D/GDP ratios by no more than an estimated 0.1 percentage point (ISPF 1993). Nonetheless, an increasing number of non-OECD countries and organizations now collect and publish internationally comparable R&D statistics, which are reported at various points in this chapter.

[37]Current OECD members are Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, South Korea, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

[38]Although PPPs technically are not equivalent to R&D exchange rates, they better reflect differences in countries' laboratory costs than do market exchange rates. (See sidebar, "Purchasing Power Parities: Preferred Exchange Rates for Converting International R&D Data.")

Advanced Technology Program Funding Slows

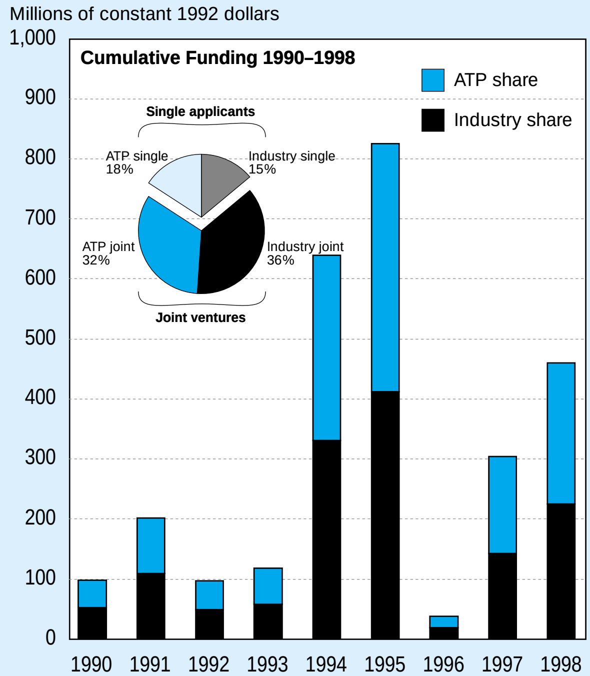
Two Federal technology partnership programs were started in the 1990s: DOC's Advanced Technology Program (ATP) and DOD's Technology Reinvestment Project (TRP). The purpose behind both programs was to spur the development and deployment of high-risk enabling technologies through an industry-driven, cost-sharing process whereby industry proposed the research and supplied at least half of the funding. Of the two programs, only ATP survives, and its budget was sharply reduced in 1996.

The cumulative shares of ATP funding from 1990 to 1998 by government and industry have been nearly the same: $1.3 billion in constant 1992 dollars. (See appendix table 2-61.) The 285 single-applicant projects have a cumulative total funding level of $851 million in constant 1992 dollars, with ATP funds accounting for 55 percent and industry funds accounting for 45 percent. The average award size across single applicants and joint ventures has been $6.1 million in constant 1992 dollars. The 146 joint ventures have had a cumulative funding level of $1.8 billion in constant 1992 dollars, of which 53 percent was provided by industry participants.

ATP runs two kinds of competitions—general and focused. Companies or consortia can submit proposals for support in any technology area(s) in the general competitions, whereas the focused competitions are for specific technologies. Proposals are selected through a peer review process and are judged on their technical merit and their potential for commercial success.

The ATP program was most active in 1994 and 1995. (See figure 2-26.) In fact, funding in these two years alone, in real terms, accounted for 53 percent of all funding over the 1990–98 period. In 1996, funding had nearly vanished to $34 million (in 1992 dollars), but it has picked up again in 1997 and 1998, with levels of $273 million and $408 million, respectively. In every year from 1990 to 1998, the ATP and industry shares have been close to 50 percent each.

Figure 2-26.
Advanced Technology Program funding



SOURCE: U.S. Department of Commerce, National Institute of Standards and Technology.

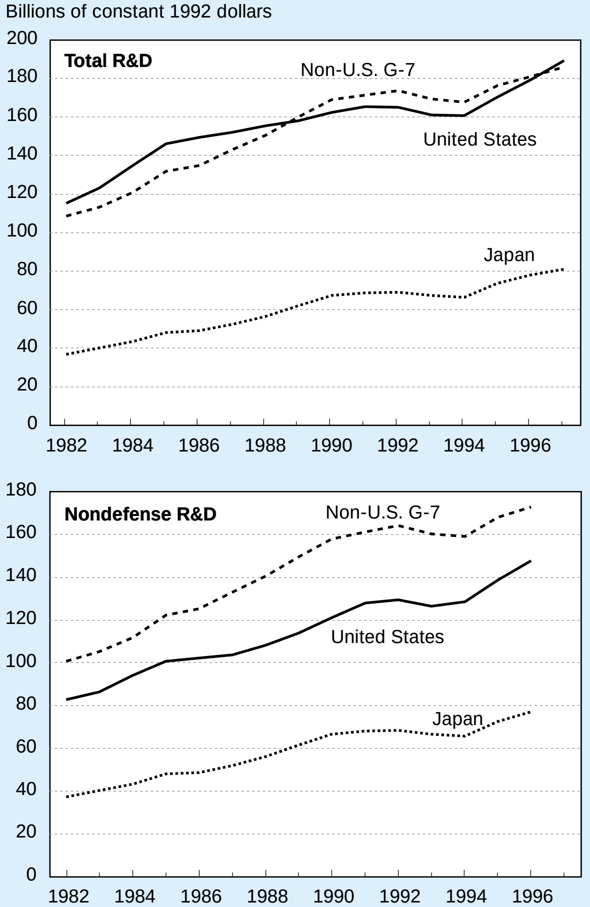
See appendix table 2-61. *Science & Engineering Indicators – 2000*

The United States accounts for roughly 43 percent of the OECD member countries' combined R&D investments; U.S. R&D investments continue to outdistance, by more than 2–to–1, R&D investments made in Japan, the second largest R&D-performing country. Not only did the United States spend more money on R&D activities in 1997 than any other country, it also spent as much by itself as the rest of the G-7 countries—Canada, France, Germany, Italy, Japan, and the United Kingdom—combined. (See appendix table 2-63.)[39] In only three other countries—the Netherlands, Australia, and Sweden—do R&D expenditures exceed 1 percent of the OECD R&D total (OECD 1999d).

In 1985, spending in G-7 countries other than the United States was equivalent to 90 percent of U.S. R&D expenditures that year. The non-U.S. total climbed steadily to peak at 105 percent of the U.S. total in 1993. Since then, however, non-U.S. G-7 R&D expenditures have slipped back to an amount equivalent to about 98 percent of the U.S. total. (See figure 2-27.) Initially, most of the United States' relative improvement vis-á-vis the other G-7 countries since 1993 resulted from a worldwide slowing in R&D performance that was more pronounced in other countries than in the United States. That is, although U.S. R&D spending stagnated or declined for several years in the early to mid-1990s, the reduction in real R&D spending in most of the other large R&D-performing countries was more striking. In Japan, Germany, and Italy, inflation-adjusted R&D spending fell for three consecutive years (1992, 1993, and 1994) at a rate of decline that exceeded similarly falling R&D spending in the United States. In fact, large and small industrialized countries worldwide

[39]International data availability has become less timely over the past several years, so 1997 is the most recent year for which R&D statistics are widely available from many countries. Part of the delay in obtaining current R&D statistics is a result of resource pressures affecting national statistical offices; part is a result of resource constraints facing international organizations that provide internationally comparable data.

Figure 2-27.
U.S. and other G-7 countries' R&D expenditures



NOTE: The non-U.S. G-7 countries are Canada, France, Germany, Italy, Japan, and the United Kingdom.

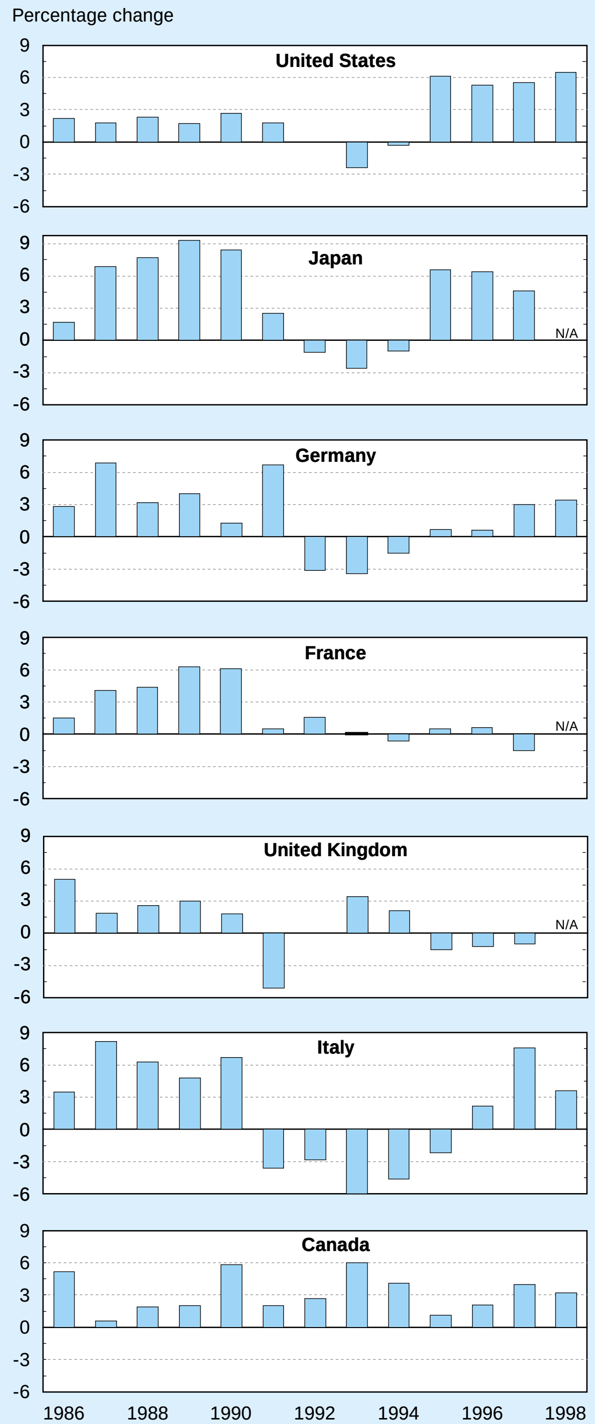
See appendix tables 2-63 and 2-64.

Science & Engineering Indicators – 2000

experienced substantially reduced R&D spending in the early 1990s (OECD 1999d). For most of these countries, economic recessions and general budgetary constraints slowed industrial and government sources of R&D support. More recently, R&D spending has rebounded in several of the G-7 countries (though not in France or the United Kingdom, according to the latest available statistics), as has R&D spending in the United States. Yet since annual R&D growth generally has been stronger in the U.S. than elsewhere (see figure 2-28), the difference between the U.S. and the combined other G-7 countries' R&D spending has continued to narrow.

Concurrent with the relative increase in the U.S. share of the G-7 countries' R&D performance has been a reduction in the U.S. R&D share of all OECD countries' R&D spending. In 1986 the United States accounted for 48 percent of the R&D reported by OECD countries; by 1997 the U.S share had dropped to less than 43 percent of the OECD R&D total. Part of this share reduction (perhaps up to 2 percentage points) resulted from the addition of several countries to OECD mem-

Figure 2-28.
Rates of change in total inflation-adjusted R&D spending



N/A = not available

NOTES: The inflation-adjusted R&D expenditures reflected in this graph are denominated in foreign currencies deflated by the countries' own GDP price deflators, and therefore are not distorted by exchange rate conversions.

See appendix table 2-63.

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Purchasing Power Parities: Preferred Exchange Rates for Converting International R&D Data

Comparisons of international statistics on R&D are hampered by the fact that each country's R&D expenditures are denominated, obviously, in its home currency. Two approaches are commonly used to normalize the data and facilitate aggregate R&D comparisons. The first method is to divide R&D by GDP, which results in indicators of relative effort according to total economic activity and circumvents the problem of currency conversion. The second method is to convert all foreign-denominated expenditures to a single currency, which results in indicators of absolute effort. The first method is a straightforward calculation, but it permits only gross national comparisons. The second method permits absolute-level comparisons and analyses of countries' sector- and field-specific R&D investments, but it entails choosing an appropriate currency conversion series.

Because (for all practical purposes) there are no widely accepted R&D-specific exchange rates, the choice is between market exchange rates (MERs) (available from IMF 1998) and purchasing power parities rates (PPPs) (available from OECD 1999d). These rates are the only series consistently compiled and available for a large number of countries over an extended period of time.

At their best, MERs represent the relative value of currencies for goods and services that are traded across borders; that is, MERs measure a currency's relative international buying power. Sizeable portions of most countries' economies do not engage in international activity, however, and major fluctuations in MERs greatly reduce their statistical utility. MERs also are vulnerable to a number of distortions—currency speculation, political events such as wars or boycotts, and official currency intervention—that have little or nothing to do with changes in the relative prices of internationally traded goods.

For these reasons, an alternative currency conversion series—PPPs—has been developed (Ward 1985). PPPs take into account the cost differences across countries of buying a similar basket of goods and services in numerous expenditure categories, including nontradables. The PPP basket is therefore representative of total GDP across countries. When the PPP formula is applied to current R&D expenditures of other major performers—such as Japan and Germany—the result is a substantially lower estimate of total research spending than that given by MERs. (See figure 2-29.) For example, Japan's R&D in 1996 totaled $85 billion based on PPPs and $130 billion based on MERs; German R&D was $40 billion and $54 billion, respectively. (By comparison, U.S. R&D was $197 billion in 1996.)

PPPs are the preferred international standard for calculating cross-country R&D comparisons wherever possible and are used in all official OECD R&D tabulations. Unfortunately, they are not available for all countries and currencies. They are available for all OECD countries, however, and are therefore used in this report. Although there is considerable difference in what is included in GDP-based PPP items and R&D expenditure items, the major components of R&D costs—fixed assets and the wages of scientists, engineers, and support personnel—are more suitable to a domestic converter than to one based on foreign trade flows. Exchange rate movements bear little relationship to changes in the cost of domestically performed R&D. (See figure 2-29.) When annual changes in Japan's and Germany's R&D expenditures are converted to U.S. dollars with PPPs, they move in tandem with such funding denominated in their home currencies. Changes in dollar-denominated R&D expenditures converted with MERs exhibit wild fluctuations that are unrelated to the R&D purchasing power of those investments. MER calculations indicate that, between 1986 and 1996, German and Japanese R&D expenditures each increased in three separate years by 20 percent or more. In reality, nominal R&D growth never exceeded 12 percent in either country during this period. PPP conversions generally mirror the R&D changes denominated in these countries' home currencies.

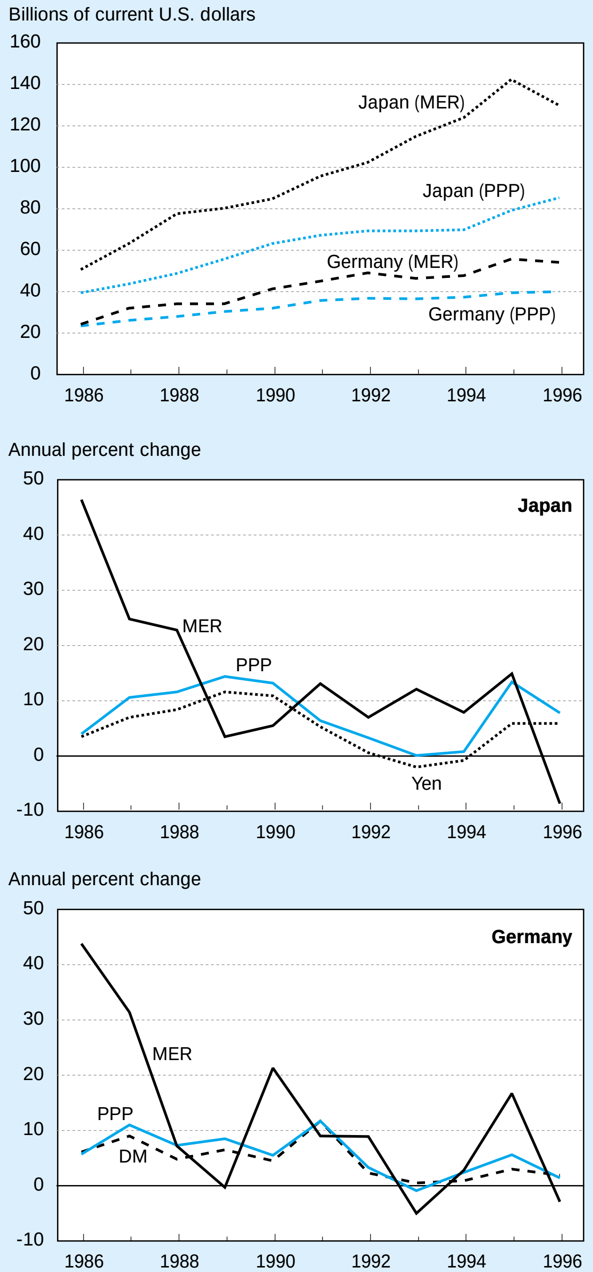
bership (thereby increasing the OECD R&D totals); worldwide growth in R&D activities, however, was a greater contributing factor to the loss of R&D share experienced by the United States. If actual "world" R&D totals were available (rather than for the OECD countries only), the decline in the U.S. share would likely be more pronounced.

Distribution of Nondefense R&D Expenditures

The policy focus of many governments on economic competitiveness and commercialization of research results has shifted attention from nations' total R&D activities to nondefense R&D expenditures as indicators of scientific and technological strength.[40] Indeed, conclusions about a country's relative standing may differ dramatically depending on whether total R&D expenditures are considered or defense-related expenditures are excluded from the totals. In absolute dollar terms, the U.S. international nondefense R&D position is still considerably more favorable than that of its foreign counterparts; the

[40]This is not to say that defense-related R&D does not benefit the commercial sector. Unquestionably, technological spillovers have occurred from defense to the civilian sector. Almost as certainly, however, the benefits are less than if these same resources had been allocated directly to commercial R&D activities. Moreover, considerable anecdotal evidence indicates that the direction of technological flow is now more commonly from commercial markets to defense applications rather than the reverse.

Figure 2-29.
Japanese and German R&D expenditures and annual changes in R&D estimates



NOTES: MER = market exchange rate; PPP = purchasing power parity; DM = deutsche mark

See appendix tables 2-1, 2-2 and 2-63.

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United States is not nearly as dominant, however, as when total R&D expenditures are compared. In 1996 (the latest year for which comparable international R&D data are available from most OECD countries), U.S. nondefense R&D was almost twice that of Japan's, but the non-U.S. G-7 countries' combined nondefense total was 17 percent more than nondefense R&D expenditures in the United States alone.

Between 1982 and 1990, growth in U.S. nondefense R&D spending was similar to nondefense R&D growth in other industrial countries (except Japan, where nondefense R&D expenditure growth was notably faster). As an equivalent percentage of the U.S. nondefense R&D total, comparable Japanese spending jumped from 45 percent in 1982 to 55 percent in 1990. (See appendix table 2-64.) During this period, Germany's annual spending equaled 26–29 percent of U.S. nondefense R&D spending. France's annual spending during this same period was equivalent to 17–18 percent of the U.S. total, and the United Kingdom's annual spending fluctuated narrowly between 14 and 16 percent of the U.S. total.

Since 1990, the worldwide slowing in R&D spending and the subsequent industrial rebound in the U.S. has narrowed the gap between U.S. nondefense R&D spending and that in the other G-7 countries. In 1996, the combined nondefense R&D spending in the six non-U.S. G-7 countries is estimated at $173 billion (in constant PPP dollars), compared with $148 billion (constant dollars) in the United States. Japanese and German nondefense spending relative to U.S. spending declined to 52 and 24 percent, respectively.

Trends in Total R&D/GDP Ratios

One of the most widely used indicators of a country's commitment to growth in scientific knowledge and technology development is the ratio of R&D spending to GDP. (See figure 2-30.) For most of the G-8 countries (that is, the G-7 countries plus the Russian Federation), the latest R&D/GDP ratio is no higher now than it was at the start of the 1990s, which ushered in a period of slow growth or decline in their overall R&D efforts. The ways in which different countries have reached their current ratios vary considerably, however.[41] The United States and Japan each reached local peaks—at 2.7 and 2.8 percent, respectively—in 1990–91. As a result of reduced or level spending by industry and government in both countries, the R&D/GDP ratios declined several tenths of a percentage point, before rising again to 2.7 and 2.9 percent. Growth in industrial R&D accounted for most of the recovery in each of these countries. Electrical equipment, telecommunications, and computer services companies have accounted for some of the strongest R&D growth since 1995 in the United States. In Japan, spending increases were highest in the electronics, ma-

[41] A country's R&D spending and therefore its R&D/GDP ratio is a function of several factors in addition to its commitment to supporting the R&D enterprise. Especially because the majority of R&D is performed by industry in each of these countries, the structure of industrial activity can be a major determinant of the level and change in a country's R&D/GDP ratio. Variations in such spending can result from differences in absolute output, industrial structure, and R&D intensity. Countries with the same size economy could have vastly different R&D/GDP ratios depending on the share of industrial output in the economy, whether the industries that account for the industrial output are traditional sites of R&D activity (for example, food processing firms generally do less R&D than do pharmaceutical companies), and whether individual firms in the same industries devote substantial resources to R&D or emphasize other activities (that is, firm-specific intensities). For example, economies with high concentrations in manufacturing (which has traditionally been more R&D intensive than nonmanufacturing or agricultural economies) have different patterns of R&D spending. See text table 2-13 for the distribution of industrial R&D performance in the G-7 countries and Sweden (which has the highest R&D/GDP ratio in the world).

Text table 2–13.
Share of industrial R&D by industry sector for selected countries

	Percent of industrial R&D performance total							
	Canada 1997	Germany 1995	France 1996	Italy 1997	Japan 1996	United Kingdom 1997	Sweden 1995	United States 1996
Total manufacturing	60.9	94.6	87.7	83.6	94.5	80.4	87.5	80.5
Food, beverages & tobacco	1.1	0.8	1.8	1.2	2.5	1.9	1.2	1.1
Textiles, fur & leather	0.6	0.6	0.6	0.4	0.8	0.3	0.2	0.3
Wood, paper, printing, publishing	1.8	0.5	0.4	0.2	1.2	0.5	3.0	2.0
Coke, ref. petrol. prod. & nucl. fuel	0.9	0.2	1.3	0.6	0.6	3.7	0.3	1.1
Chemicals & chemical products	8.5	17.9	18.6	13.9	15.8	29.6	16.3	13.0
Chemicals (less Pharmaceuticals)	2.1	13.3	6.3	5.9	9.2	7.1	2.0	6.3
Pharmaceuticals	6.3	4.6	12.3	8.0	6.6	22.5	14.3	6.8
Rubber & plastic products	0.4	1.5	2.5	1.9	2.6	0.6	1.0	1.0
Non-metallic mineral products	0.1	1.0	1.2	0.3	2.1	0.5	0.5	0.3
Basic metals	1.8	1.0	1.7	1.0	3.5	0.6	1.2	0.5
Fabricated metal products	0.9	1.4	1.2	2.7	1.5	0.9	1.1	1.1
Machinery eq., instruments & trans. equip.	44.1	69.0	57.7	61.3	63.1	41.5	62.5	59.6
Machinery, n.e.c.	1.9	11.3	4.6	5.3	8.7	5.8	10.8	4.2
Office, account. & computing machinery	4.1	3.9	2.6	3.7	9.9	1.1	1.4	8.8
Electrical machinery	0.9	7.2	3.4	4.8	10.9	4.4	1.6	2.3
Electro. equip.(radio, TV & comm.)	23.8	10.0	11.5	19.4	16.1	6.9	19.9	13.2
Instruments, watches & clocks	1.2	6.0	9.5	1.8	3.6	3.5	6.9	8.4
Motor vehicles	1.8	21.2	11.9	14.7	12.8	10.1	16.4	11.1
Other transport equipment	10.3	9.4	14.3	11.6	1.1	9.8	5.5	11.6
Aerospace	10.3	8.1	13.7	9.7	0.7	9.3	5.1	11.2
Ships, other transport nec.	0.1	1.2	0.6	2.0	0.3	0.4	0.5	0.3
Furniture, other manufacturing nec.	0.7	0.6	0.6	0.1	0.8	0.3	0.2	NA
Electricity, gas & water	2.6	0.4	3.1	3.0	1.1	1.4	0.9	0.2
Construction	0.2	0.3	0.7	0.3	2.2	0.1	0.5	0.2
Total services	33.5	3.5	6.9	13.1	4.2	17.5	10.0	19.5
Wholesale, retail trade, motor veh. repair etc.	6.4	0.1	NA	0.2	NA	0.1	NA	4.4
Hotels & restaurants	NA	NA	NA	0.0	NA	NA	NA	0.2
Transport & storage	0.2	0.2	2.9	0.2	0.1	0.1	0.2	0.2
Communications	2.1	NA	NA	4.1	2.4	5.2	2.5	2.8
Financ. intermediation (inc. insur.)	5.5	0.1	NA	0.0	NA	NA	NA	0.9
Real estate, renting & bus. activities	19.3	2.5	3.9	8.4	1.8	12.0	7.1	NA
Computer & related activities	6.8	0.4	2.3	1.1	1.8	7.4	1.5	5.1
Research & development	9.6	0.7	NA	5.9	NA	3.5	5.0	3.8
Other business activities nec.	2.9	1.4	1.6	1.4	NA	1.2	0.6	NA
Comm., soc. & pers. serv. activ.,etc.	NA	0.1	NA	0.2	NA	0.1	0.2	NA

NA= Not available separately

NOTE: The underlying OECD detailed data do not sum to 100 percent.

SOURCE: Organisation for Economic Co-operation and Development (OECD), ANBERD Database (DSTI/EAS Division), 1999.

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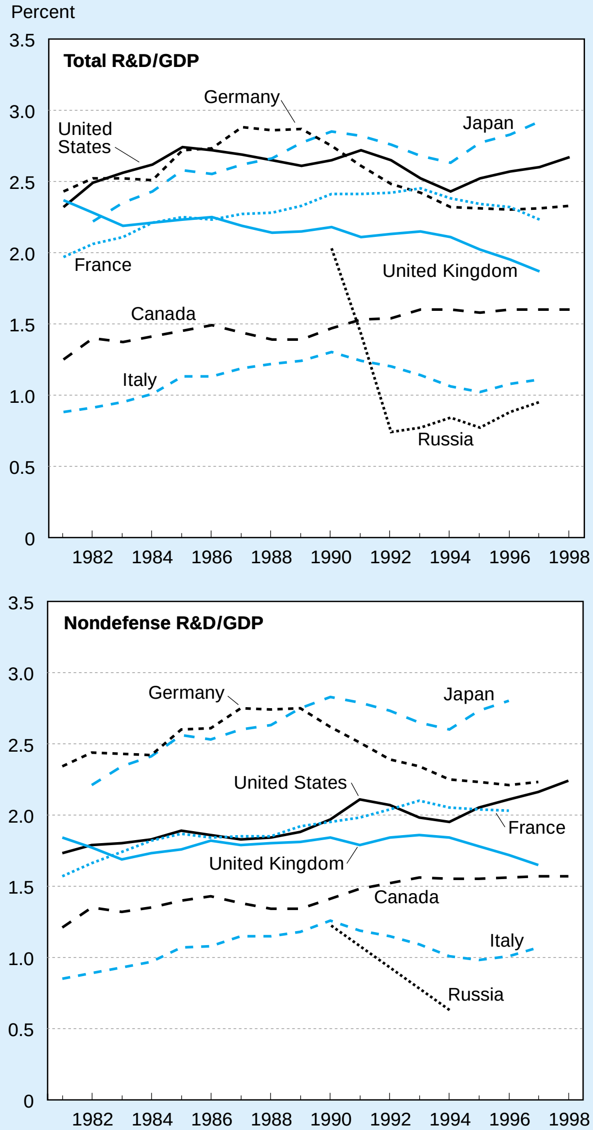
chinery, and automotive sectors and appear to be associated mainly with a wave of new digital technologies (IRI 1999). In addition, Japan's national government also has contributed to some of the renewed vigor in Japan's R&D spending. (See NSF 1997 for a summary of the Japanese government's intent to double Japan's R&D budget.)

By comparison—and with the notable exception of Canada, for which the R&D/GDP ratio has remained relatively level since the early 1990s—the other G-8 countries each report lower R&D shares now than at the beginning of the decade. The smallest share reductions occurred in Italy, the United Kingdom, and France (declining about two-tenths of a percentage point in each country, to current ratios of 1.0, 1.9, and 2.3 percent, respectively). In Germany, the R&D/GDP ratio fell from 2.9 percent at the end of the 1980s, before reunification, to its current level of 2.4 percent. The end of the Cold War and collapse of the Soviet Union had a drastic effect on Russia's R&D enterprise. R&D spending in Russia was estimated at 1.4 percent of GDP in 1991; that figure plummeted to 0.7 percent in 1992. Moreover, the severity of this R&D decline is masked somewhat in that while the R&D share was falling, it also was a declining share of a declining GDP. By 1997, R&D spending in Russia had inched back to about 1.0 percent of GDP.

Figure 2-30.
R&D as a percentage of GDP, G-8 countries



See appendix tables 2-63 and 2-64.

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Text table 2–14.
R&D as a percentage of gross domestic product

Sweden	3.85	Russian Federation	0.95
Japan	2.92	Venezuela	0.89
South Korea	2.89	Spain	0.86
Finland	2.78	Brazil (1996)	0.76
Switzerland (1996)	2.74	Poland	0.76
United States	2.60	Hungary	0.73
Germany	2.31	Cuba	0.70
Israel	2.30	South Africa	0.69
France	2.23	China	0.65
Netherlands (1996)	2.09	Portugal	0.65
Denmark	2.03	Chile	0.64
China (Taipei)	1.92	Indonesia (1995)	0.50
United Kingdom	1.87	Greece (1993)	0.48
Australia (1996)	1.68	Turkey (1996)	0.45
Norway	1.68	Uruguay	0.42
Canada	1.60	Colombia	0.41
Belguim (1995)	1.58	Argentina	0.38
Iceland	1.56	Panama	0.38
Austria	1.52	Malaysia (1994)	0.34
Singapore	1.47	Bolivia (1996)	0.33
Ireland	1.43	Mexico	0.42
Czech Republic	1.19	The Philippines (1992)	0.21
Slovak Republic	1.18	Thailand (1996)	0.12
Costa Rica (1996)	1.13	Hong Kong (1996)	0.10
New Zealand	1.10	Ecuador (1996)	0.08
Italy	1.08		

NOTES: Unless noted otherwise, data are for 1997.
Data for Israeli and China (Taipei) include nondefense R&D only.

Total OECD	2.17
North America	2.36
European Union	1.84

SOURCES: Organisation for Economic Co-operation and Development (OECD 1999), Centre for Science Research and Statistics (CSRS 1999), Red Iberomericana de Indicatores de Ciencia y Tecnologia (RICYT 1998), Israel Central Bureau of Statistics (1998), South Africa FRD (1998), National Science Council (1998), and Pacific Economic Cooperation Council (PECC 1997).

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Overall, the United States ranked sixth among OECD countries in terms of reported R&D/GDP ratios for the 1995–97 period. (See text table 2-14.) Sweden leads all countries with 3.9 percent of its GDP devoted to R&D—followed by Japan and South Korea (2.9 percent); Finland (2.8 percent); and Switzerland (2.7 percent). In general, southern and eastern European countries tend to have R&D/GDP ratios below 1.5 percent, whereas northern European nations and non-European OECD countries report R&D spending shares above 1.5 percent.

Nondefense R&D/GDP Ratios

Compared with total R&D/GDP ratios, the relative position of the United States is slightly less favorable if only nondefense R&D is considered. Japan's nondefense R&D/GDP ratio (2.8 percent) exceeded that of the United States (2.1 percent) in 1996, as it has for years. (See figure 2-30 and appendix table 2-64.) The nondefense R&D ratio of Germany (2.2 percent) slightly exceeded that of the United States (again, in contrast to total R&D). The 1996 nondefense ratio for France (2.0 percent) was slightly below the U.S. ratio; those for the United Kingdom (1.7 percent), Canada (1.6 percent), and Italy (1.0 percent) were much lower. The most recent nondefense R&D/GDP ratio for Russia was a 0.6 percent share in 1994.

Consistent with overall R&D funding trends, however, the U.S. nondefense R&D/GDP ratio has been improving relative to each of the G-8 countries since 1994, when ratios reported for Japan and Germany exceeded that for the United States. France also reported devoting more of its economic output to nondefense R&D activities than did the United States, and the relative ratio of U.K. nondefense R&D spending to GDP was about equal to that in the United States. Led by industry's investments in research and predominantly development spending, the U.S. nondefense R&D/GDP ratio now matches or exceeds each of the world's other major R&D performing countries (except Japan).

Emerging Countries' R&D Investments

Outside the European region, R&D spending has intensified considerably since the early 1990s. Several Asian countries—most notably South Korea and China—have been particularly aggressive in expanding their support for R&D and S&T-based development.[42] In Latin America and the Pacific region, other non-OECD countries also have attempted to substantially increase R&D investments during the past several years (APEC/PECC 1997; RICYT 1998).[43]

Even with recent gains, however, most non-European (non-OECD) countries invest a smaller share of their economic output on R&D than do OECD members (with the exception of Israel—whose reported 2.3 percent nondefense R&D/GDP ratio ranks eighth in the world). With the apparent exception of Costa Rica, all Latin American countries for which such data are available report R&D/GDP ratios below 1 percent. (See text table 2-14.) This distribution is consistent with broader indicators of economic growth and wealth. However, many of these countries also report additional S&T-related expenditures on human resources training and S&T infrastructure development that are not captured in R&D and R&D/GDP data (RICYT 1998).

R&D in the Russian Federation in Transition

As recently as 1990, R&D accounted for about 2 percent of the Soviet Union's GDP, with about 40 percent of that amount expended on defense-related activities (Gohkberg, Peck, and Gacs 1997).[44] Indeed, the most advanced aspects of Soviet R&D efforts were undertaken in state-owned enterprises devoted to national security; much of the remaining R&D was performed in other large public industrial institutions in applied research fields that overlapped defense concerns. Most of the basic research was and continues to be in the physical sciences and engineering fields.

[42]Also see NSF (1993) and NSF (1995) for a discussion of S&T trends in several Asian countries. See NSF (1996) for information on growth in S&T activities in Europe.

[43]In addition to expanding their R&D investments, an increasing number of countries worldwide have expended considerable efforts to collect and publish science and technology (including R&D) statistics that are internationally comparable. One such effort is coordinated by the Iberoamerican Network of Science and Technology Indicators (RICYT). The Network aims to design, collect, and publish S&T indicators, as well as to train professionals specialized in these subjects (Albornoz and Poluch 1999). Together with assistance from the Organization of American States (OAS) and the Iberoamerican Program on Science and Technology for Development, RICYT has published several S&T indicator reports (available at <<http://www.unq.edu.ar/ricyt>>). The Network has the participation of all countries in the Americas, as well as that of Spain and Portugal. Similar efforts have been underway for Pacific-based economies that are members of the Asia-Pacific Economic Cooperation (APEC) and the Pacific Economic Cooperation Council (PECC).

[44]R&D data for the Russian Federation are taken from Centre for Science Research and Statistics surveys designed to collect such statistics in accordance with OECD international standards.

The introduction of a market economy to Russia brought about drastic economic restructuring, including a sharp decline in the dominance of state-owned enterprises and a 25 percent shrinkage in real GDP in just two years (IMF 1998). These trends, in turn, brought about major R&D downsizing; real R&D expenditures in 1992 collapsed to only 30 percent of the inflation-adjusted levels reported for 1990 (CSRS 1999). That is, real spending on R&D fell 70 percent with a resultant R&D/GDP ratio of about 0.7 percent. (See text table 2-15.) Reflecting the lack of core budgets, between 1990 and 1992 entire research institutes closed—including many well-equipped laboratories of the former military-industrial complex—and an estimated 19 percent of all researchers left their government R&D laboratories for the commercial sector or retirement or for other reasons, including emigration.[45]

Between 1992 and 1995, Russian R&D spending continued to deteriorate, though at a slower pace, falling 25 percent in real terms (for a total decrease of 78 percent since the start of the decade) (CSRS 1999; OECD 1998b). The rate at which researchers left their labs accelerated, however; the number of researchers at government facilities declined 39 percent during the 1992–95 period, reflecting the effect of low and unpaid salaries, declining budgets for capital and research equipment, and generally inhospitable working conditions.

In terms of R&D spending, the situation in Russia has improved slightly since 1995. Fueled by government and industrial spending, growth in R&D exceeded inflation in 1996 and 1997. Similarly, funds from foreign sources (including funding from

[45]Other former communist countries have experienced similar patterns of initial decline and restructuring in their R&D enterprise. In the transition toward market economies, however, the pattern has varied considerably among countries, reflecting the diversity of their economic and social histories and experiences (e.g., business orientation, technological openness, and role of higher education). For a review of country-specific differences and recent developments in Hungary, Poland, the Czech Republic, Slovakia, Romania, and Russia, see Radosevic and Auriol (1999).

Text table 2–15.
Indicators of R&D in the Russian Federation

	R&D (Billions of 1989 rubles)	R&D/ GDP	R&D Personnel		
			Total*	Researchers	Technicians
			(thousands)		
1990	10.898	2.03	1,943	993	235
1991	7.290	1.43	1,678	879	201
1992	3.225	0.74	1,533	804	181
1993	3.055	0.77	1,315	645	134
1994	2.930	0.84	1,106	525	116
1995	2.446	0.77	1,061	519	101
1996	2.603	0.88	991	485	88
1997	2.797	0.95	935	455	80

* Includes science and engineering researchers, technicians, and other supporting staff.

SOURCE: Center for Science Research and Statistics (CSRS) *Russian Science and Technology at a Glance: 1998* (Moscow: CSRS, 1999)

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the European Union and the U.S. Civilian Research Foundation, among others) tripled between 1995 and 1997 and now account for 7 percent of domestic R&D spending in Russia (CSRS 1999). In spite of these recent gains, real R&D spending remains 13 percent below the levels reported for 1992 and 75 percent below the estimated levels at the beginning of the decade. Furthermore, the outflow of researchers from such activities is still an important concern, as is the belief that the younger generation is not choosing science and engineering careers to the same extent as previously. Between 1995 and 1997, an estimated 65,000 scientists and engineers left their R&D work, resulting in a researcher workforce level (455,000) that was less than half of the estimated 1990 level (993,000).

International R&D by Performer, Source, and Character of Work

Performing Sectors

The industrial sector dominates R&D performance in each of the G-7 countries. (See figure 2-31.) Industry performance shares for the 1996–98 period ranged from a little more than 70 percent in the United States and Japan to less than 54 percent in Italy. Industry's share was between 60 and 70 percent in Germany, France, the United Kingdom, and Canada.[46] Most of the industrial R&D performance in these countries was funded by industry. Government's share of funding for industry R&D performance ranged from as little as 1 percent in Japan to 15 percent in the United States. (See appendix table 2-65.) By comparison, industry performance in Russia accounted for a 66 percent share of the total. However, government was the source of half of these funds (as contrasted with government's 15 percent or smaller shares in the G-7 countries), and industry itself funded just 40 percent of the Russian industrial R&D performance total.[47]

In most of these countries, the academic sector was the next-largest R&D performer (at about 12 to 25 percent of the performance total in each country).[48] Academia often is the primary location of research (as opposed to R&D) activities, however. Government was the second-largest R&D performing sector in France (which included spending in some sizeable government laboratories) and the U.S. (which includes FFRDCs), as it was in Russia (accounting for 28 percent of that nation's R&D effort). By comparison, government's R&D performance share was smallest in Japan, at about 10 percent of the country's total.

Sources of Funds

Industry R&D Funding

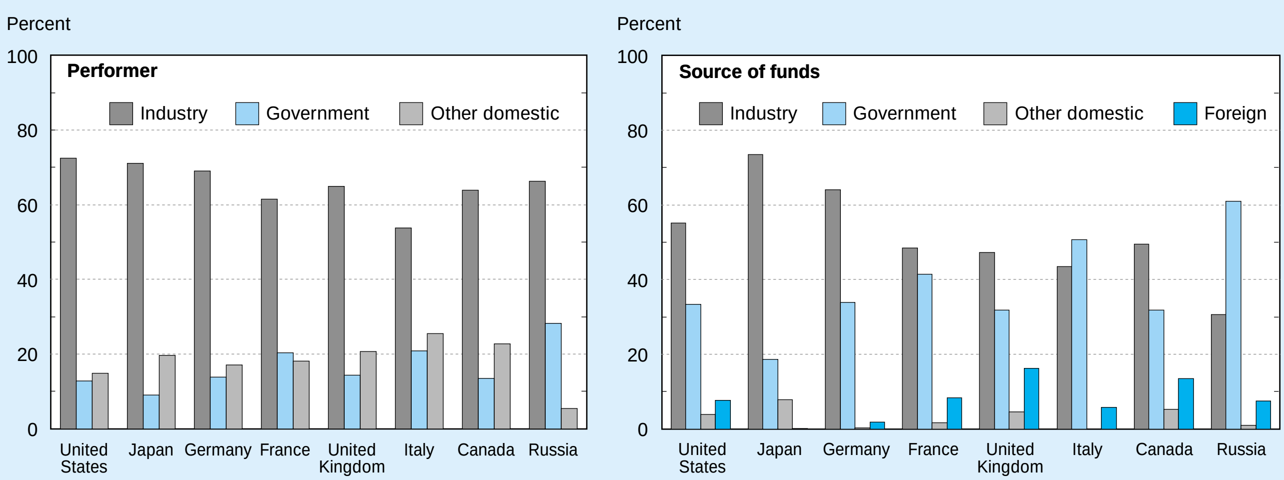
Consistent with the fact that the industrial sector performs most of these countries' R&D activities, it provides the great-

[46]See text table 2-13 for the distribution of industrial R&D performance in the G-7 countries and Sweden. For detailed data on industry-specific R&D activities in other OECD countries, see OECD 1999b.

[47]Although the economic structure of the Russian system still differs considerably from that of the G-7 countries, these data were compiled and adjusted by the Russian R&D statistics organization, CSRS (1999), according to OECD sector categories to allow international comparison.

[48]The national totals for Europe, Canada, and Japan include the research component of general university funds (GUF) block grants—not to be confused with basic research—provided by all levels of government to the academic sector. Therefore, at least conceptually, the totals include academia's separately budgeted research and research undertaken as part of university departmental R&D activities. In the United States, the Federal Government generally does not provide research support through a GUF equivalent, preferring instead to support specific, separately budgeted R&D projects. On the other hand, a fair amount of state government funding probably does support departmental research at public universities in the United States. Data on departmental research, considered an integral part of instructional programs, generally are not maintained by universities. U.S. totals may thus be underestimated relative to the R&D effort reported for other countries.

Figure 2-31.
R&D expenditures, by country, performer, and source: 1996–98



NOTE: Foreign performers are included in the "industry" and "other domestic" performing sectors.

See appendix table 2-65.

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est proportion of financial support for R&D in the G-7. Shares for this sector, however, differed from one country to another. Industry provided more than 70 percent of R&D funds in Japan; 64 percent in Germany; 55 percent in the United States; and between 44 and 49 percent in the United Kingdom, Italy, France, and Canada. In Russia, industry provided about 30 percent of the nation's R&D funding; government provided the largest share (61 percent of the country's 1997 R&D total). In most of these countries (except Russia and Italy, where it was largest), government was the second-largest source of R&D funding. In each of these eight countries, government provided the largest share of the funds for academic R&D performance.

Declining Government R&D

The most notable trend among the G-7 countries, however, has been the relative decline in government R&D funding in the 1990s. Indeed, this pattern of reduced governmental R&D support is apparent throughout the OECD, and especially in European countries (Caracostas and Muldur 1998). In 1997, roughly one-third of all R&D funds were derived from government sources—down considerably from the 45 percent share reported 16 years earlier. (See text table 2-16.) Among all OECD countries, government accounts for the highest funding share in Portugal (68 percent of its 1997 R&D total) and the lowest share in Japan (19 percent in 1996). Part of the relative decline reflects the effects of budgetary constraints, economic pressures, and changing priorities in government funding (especially the relative reduction in defense R&D in several of the major R&D-performing countries—notably France, the United Kingdom, and the United States). Part reflects the absolute growth in industrial R&D funding as a response to increasing international competitive pressures in the marketplace, irrespective of government R&D spending patterns—thereby increasing the relative share of industry's funding vis-á-vis government's. Both of these considerations are reflected in funding patterns for industrial R&D performance alone: In 1981, government provided 23 percent of the funds used by industry in the conduct of R&D within OECD countries, whereas by 1997 government's share of the industry R&D total had fallen by more than half, to 10 percent of the total. In most OECD countries (as in the U.S.), government support to business R&D is skewed toward large firms (OECD 1999a).

Rising Foreign R&D

The R&D funding share represented by funds from abroad ranged from as little as 0.1 percent in Japan to more than 16 percent in the United Kingdom. Foreign funding—predominantly from industry for R&D performed by industry—is an important and growing funding source in several countries and reflects the increasing globalization of industrial R&D activities overall. Although the growth pattern of foreign funding has seldom been smooth, it now accounts for more than 20 percent of industry's domestic performance totals in Canada and the United Kingdom and approximately 10 percent of industry R&D performed in France and Italy. (See figure 2-32.) Such funding takes on even greater importance in many of the smaller OECD countries, as well as in less industrialized countries (OECD 1999d). In the United States, approximately 8 percent of funds spent on industry R&D performance in 1996 are estimated to have come from majority-owned affiliates of foreign firms investing domestically. This amount was considerably more than the 3 percent funding share provided by foreign firms in 1980.[49]

[49]Unlike for other countries, there are no data on foreign sources of U.S. R&D performance. The figures used here to approximate foreign involvement are derived from the estimated percentage of U.S. industrial performance undertaken by majority-owned (i.e., 50 percent or more) nonbank U.S. affiliates of foreign companies. In short, the U.S. foreign R&D totals represent industry funding based on foreign ownership regardless of originating source, whereas the foreign totals for other countries represent flows of foreign funds from outside the country to any of its domestic performers.

Text table 2–16.
Sources of total and industry R&D performed in OECD countries, selected years
(Percent)

	1981	1986	1991	1997
OECD total R&D financed by				
Industry	51.2	54.1	58.7	62.3
Government	45.0	42.0	35.8	31.4
Other domestic sources	2.5	2.4	3.4	3.8
Foreign sources	1.3	1.5	2.1	2.5
OECD industry R&D financed by				
Government	22.6	21.8	15.0	10.2
Industry and other sources	77.4	78.2	85.0	89.8

NOTE: Includes all countries that were members of the OECD in the year reported, therefore the number of countries included may differ from one year to the next.

SOURCE: OECD Main Science and Technology Indicators Database (April 1999).

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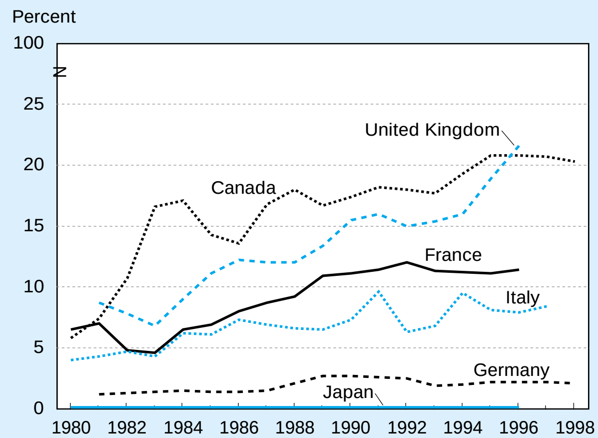
Figure 2-32.
Proportion of industrial R&D expenditures financed from foreign sources



See appendix table 2-72.

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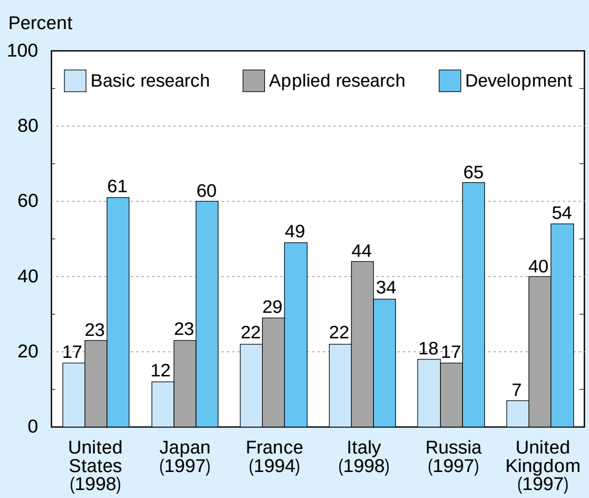
Character of R&D Effort

Not all of the G-8 countries categorize their R&D expenditures into character of work classifications (that is, basic research, applied research, or development), and for several countries that do utilize this taxonomy, the data are somewhat dated (OECD 1999c). Nonetheless, where these data exist, they are indicative of the relative emphasis that a country places on supporting fundamental scientific activities—the seed corn of economic growth and technological advancement.

The United States expends about 17 percent of its R&D on activities that performers classify as basic research. (See figure 2-33.) Much of this research is funded by the Federal Government and is performed in the academic sector. The largest share of this basic research effort is in support of the life sciences.

Basic research accounts for a similar portion (18 percent) of the R&D total in the Russian Federation. In comparison with U.S. patterns, however, a considerably greater share is for engineering research activities. In Japan, a comparatively smaller amount (12 percent) of the national R&D performance effort is for basic research, but as in Russia engineering fields receive the largest share of these funds. Conversely, basic research accounts for more than 20 percent of total R&D performance reported in Italy, France, and Germany. Furthermore, basic research would likely account for a similar share of the United Kingdom's R&D were these data available and published for the academic and nonprofit sectors—traditional locations for basic research activities. Except in Italy (where applied research was dominant), development activities accounted for the largest share of national totals, with most of the experimental development work underway in their respective industrial sectors.

Figure 2-33.
Distribution of R&D by character of work, in selected G-8 countries



NOTES: The character of work for 6 percent of Japan's R&D is unknown. The U.K splits are for industrial and government performers only. R&D character of work data for the higher education and nonprofit sectors (21 percent of the national total) are unavailable. For Germany, 21 percent of its 1993 R&D was basic research; the rest was undistributed. Canada does not report any of these data. Because of rounding, detail may not sum to totals.

SOURCES: Organization for Economic Co-operation and Development (OECD). 1999c. *Basic Science and Technology Statistics: 1998* (on diskette). Paris: OECD; Center for Science Research and Statistics (CSRS) 1999. *Russian Science and Technology at a Glance: 1998*. Moscow: CSRS.

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International Comparisons of Government R&D Priorities

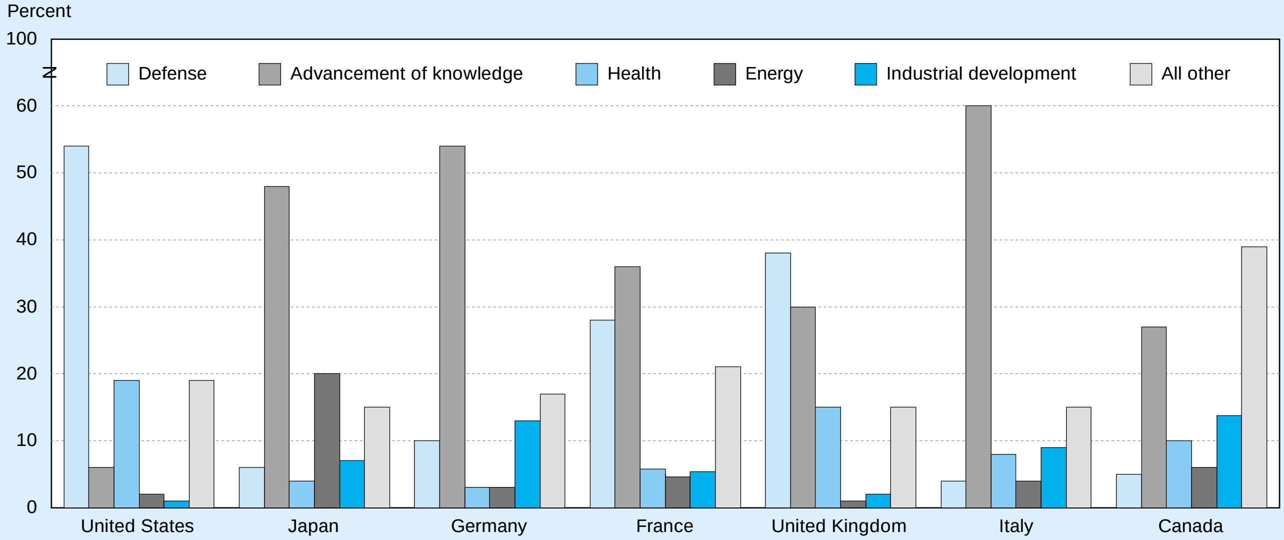
The downturn in R&D growth within OECD countries has been disproportionately caused by flat or declining government funding of R&D since the late 1980s. These developments reflect and add to worldwide R&D landscape changes that present a variety of new challenges and opportunities. The following sections highlight government R&D funding priorities in several of the larger R&D-performing nations, summarize broad policy trends, and detail indirect support for research that governments offer their domestic industries through the tax code.

Funding Priorities by National Objective

A breakdown of public expenditures by major socioeconomic objectives provides insight into governmental priorities, which differ considerably across countries.[50] In the United States, 54 percent of the government's $74 billion R&D investment during 1998 was devoted to national defense. This share compares with the 38 percent defense share in the United Kingdom (of an $9 billion government total); 28 percent in France (of $13 billion); and 10 percent or less each in Germany, Italy, Canada, and Japan. (See figure 2-34 and appendix table 2-66.) These recent figures represent substantial cutbacks in defense R&D in the United States, the United Kingdom, and France—where defense accounted for 63 percent, 44 percent, and 40 percent of government R&D funding, respectively, in 1990. However, defense-related R&D also seems particularly difficult to account for in many countries' national statistics. (See sidebar, "Accounting for Defense R&D: Gap Between Performer- and Source-Reported Expenditures.")

[50] Data on the socioeconomic objectives of R&D funding are rarely obtained by special surveys; they are generally extracted in some way from national budgets. Because those budgets already have their own methodology and terminology, these R&D funding data are subject to comparability constraints not placed on other types of international R&D data sets. Notably, although each country adheres to the same criteria for distributing their R&D by objective—as outlined in OECD's Frascati Manual (OECD 1994)—the actual classification may differ among countries because of differences in the primary objective of the various funding agents. Note also that these data reflect government R&D funds only, which account for widely divergent shares and absolute amounts of each country's R&D total.

Figure 2-34.
Government R&D support, by country and socioeconomic objective: 1997–98



NOTES: R&D is classified according to its primary government objective, although it may support any number of complementary goals. For example, defense R&D with commercial spinoffs is classified as supporting defense, not industrial development. R&D for the advancement of knowledge is not equivalent to basic research.

See appendix table 2-66. *Science & Engineering Indicators – 2000*

International Nondefense Functions

Japanese, German, and Italian government R&D appropriations in 1997 were invested relatively heavily (48 percent or more of the $18 billion total for Japan, 54 percent of Germany's $16 billion total, 60 percent of the $6 billion total in Italy) in advancement of knowledge—that is, combined support for advancement of research and general university funds (GUF). Indeed, the GUF component of advancement of knowledge—for which there is no comparable counterpart in the United States—represents the largest part of government R&D expenditure in most OECD countries.[51]

The emphasis on health-related research is much more pronounced in the United States than in other countries. This emphasis is especially notable in the support of life sciences in academic and similar institutions. In 1998, the U.S. government devoted 19 percent of its R&D investment to health-related R&D, making such activities second only to defense. (Direct comparisons between health and defense R&D are complicated because most of the health-related R&D is research, whereas about 90 percent of defense R&D is development.) By comparison, health R&D support ranges between 9 and 15 percent of total spending in the governmental R&D budgets of the United Kingdom, Italy, and Canada.

Different activities were emphasized in other countries' governmental R&D support statistics. Japan committed 20 percent of governmental R&D support to energy-related activities, reflecting the country's historical concern about its high dependence on foreign sources of energy. In Canada, 12 percent of the government's $3 billion in R&D funding was directed toward agriculture. Space R&D received considerable support in the United States and France (11 percent of the total in each country), whereas industrial development accounted for 9 percent or more of governmental R&D funding in Germany, Italy, and Canada. Industrial development programs accounted for 7 percent of the Japanese total but just 0.5 percent of U.S. R&D. The latter figure is understated relative to other countries as a result of data compilation differences.

[51]In the United States, "advancement of knowledge" is a budgetary category for research unrelated to a specific national objective. Furthermore, whereas GUF is reported separately for Japan, Canada, and European countries, the United States does not have an equivalent GUF category: Funds to the university sector are distributed to address the objectives of the Federal agencies that provide the R&D funds. Nor is GUF equivalent to basic research. The treatment of GUF is one of the major areas of difficulty in making international R&D comparisons. In many countries, governments support academic research primarily through large block grants that are used at the discretion of each individual higher education institution to cover administrative, teaching, and research costs. Only the R&D component of GUF is included in national R&D statistics, but problems arise in identifying the amount of the R&D component and the objective of the research.

Government GUF support is in addition to support provided in the form of earmarked, directed, or project-specific grants and contracts (funds for which can be assigned to specific socioeconomic categories). In the United States, the Federal Government (although not necessarily state governments) is much more directly involved in choosing which academic research projects are supported than national governments in Europe and elsewhere. Thus, these socioeconomic data are indicative not only of relative international funding priorities but also of funding mechanisms and philosophies regarding the best methods for financing research. For 1997, the GUF portion of total national governmental R&D support was 47 percent in Italy, about 38 percent in Japan and Germany, and just under 20 percent in the United Kingdom, Canada, and France.

Accounting for Defense R&D: Gap Between Performer- and Source-Reported Expenditures

In many OECD countries, including the United States, total government R&D support figures reported by government agencies differ substantially from those reported by performers of R&D work. Consistent with international guidance and standards (OECD 1994), however, most countries' national R&D expenditure totals and time series are based primarily on data reported by performers. This convention is preferred because performers are in the best position to indicate how much they spent in the actual conduct of R&D in a given year and to identify the source of their funds. Although there are many reasons to expect funding and performing series to differ—such as different bases used for reporting government obligations (fiscal year) and performance expenditures (calendar year)—the gap between the two R&D series has widened during the past several years. Additionally, the divergence in the series is most pronounced in countries with relatively large defense R&D expenditures.

For the United States, the reporting gap has become particularly acute over the past several years. In the mid-1980s, performer-reported Federal R&D exceeded Federal reports by $3 to $4 billion annually—5 to 10 percent of the government total. This pattern reversed itself toward the end of the decade; in 1989 government-reported R&D total exceeded performer reports by $1 billion. The gap has since grown to about $5 billion. In other words, about 7 percent of the government total in the late 1990s is unaccounted for in performer surveys. (See figure 2-35.)

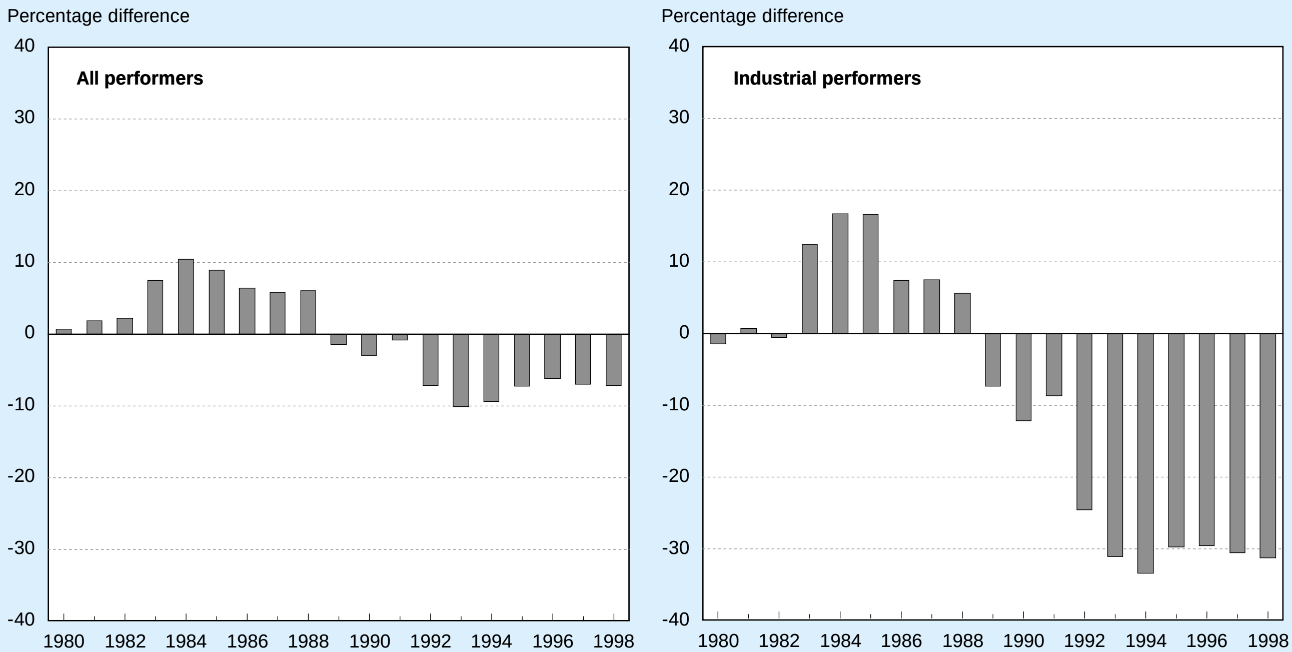
The difference in Federal R&D totals is primarily in DOD development funding of industry (primarily aircraft and missile firms). For 1997, Federal agencies reported $31.4 billion in total R&D obligations provided to industrial performers, compared with an estimated $21.8 billion in Federal funding reported by industrial performers. (DOD reports industry R&D funding of $24.2 billion, whereas industry reports using $12.6 billion of DOD's R&D funds.) Overall, industry-wide estimates equate to a 31 percent paper "loss" of Federally reported R&D support. (See figure 2-35.)

To investigate causal factors for the reporting gap, NSF—working with DOD contract-specific data—conducted on-site interviews with carefully selected companies that perform Federal R&D for DOD. Companies were asked about their R&D activities, data collection and reporting methods, and subcontracting practices. They also were asked to volunteer information about other factors that might influence the growing reporting difference. On the basis of these interviews and supplemental data analyses, the following factors appear to contribute most to the observed data gap.

Shifts in the composition of R&D, test, and evaluation (RDT&E) contracts during the past 10 years—since the end of the Cold War—introduced numerous changes in DOD's budgeting choices. Between 1991 (the last year that Federal funding and performing totals were relatively close) and 1998, DOD procurement spending (in inflation-adjusted terms) fell by 50 percent, whereas RDT&E spending declined by a relatively modest 7 percent. Concurrently, the proportion of DOD's RDT&E funding of traditional R&D program activities such as missile and space systems, tanks, ships, and other weapons systems has decreased; funding of more generalized technical, analytical and professional service contracts has increased. This trend has been accompanied by the emergence of new, nontraditional contractors (including large communication carriers and small high-technology firms) and firms specializing in program support activities within the DOD-funded R&D-performing industrial sector. Consequently, an increasing share of what DOD now funds, and therefore reports as R&D, is not necessarily perceived as R&D by industry performers. Industry representatives also mentioned significant changes in DOD's overall budget environment whereby RDT&E funds are now used to update military equipment under an emerging procurement management concept called "repeated R&D," whereby new technology is being incorporated on an ongoing basis into military systems. The effect is that RDT&E appropriations are now funding activities that could have been considered production 10 years ago. In short, there has been a change in what constitutes the R&D activity that is not similarly captured from Federal and industry respondents.

As a result of major changes in DOD's efforts to streamline its procurement environment and practices, the use of large, flexible, multiyear, multi-agency, indefinite order-type contract vehicles has become increasingly common. These contracts, which can be used

Figure 2-35.
Difference in U.S. performer-reported versus agency-reported Federal R&D



NOTE: Difference is defined as the percentage of federally reported R&D.

See appendix table 2-59.

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by nearly every Federal agency, significantly reduce administrative and procurement actions needed to acquire services and technical support from previously selected contractors. They also have very high funding "ceilings" that allow government agencies to order tasks as needed. These contract vehicle characteristics tend to hide the ultimate funding source for particular activities and confuse the original "color of money" (i.e., the nature of the originating appropriation accounts). The effects of these procurement reforms were widespread in 1992 and 1993.

Finally, the consolidation of the defense and aerospace R&D business (see figure 4-10 in NSB 1998), as well as other corporate mergers and acquisitions, has considerably complicated industries' tracking of defense-related R&D. Few firms (especially extremely large, diversified companies) maintain award-specific data on R&D contracts for their many subsidiaries. Consequently, R&D-intensive activities of acquired firms may not be visible at corporate headquarters responding to national R&D surveys. This reporting problem is magnified with recent growth in R&D outsourcing. In such circumstances, the subcontracted ("routine technical service") activity often is performed by companies with only scant knowledge of the original funding source and perhaps even less knowledge on the overall DOD R&D objective to which their work is contributing.

The relative importance of these considerations in quantifying these data differences is unknown. Clearly, however, a variety of factors affect the collection of consistently reported R&D data from performers and funders. A similar mismatching of Federal R&D to academia as reported by universities and Federal agencies is now appearing in the data series. In this instance, however, totals reported by universities exceed those reported by Federal respondents. Indeed, other countries also have difficulty tracking and matching performer and source data (see NSB 1998)—indicative of the transitional changes affecting the S&E enterprise globally.

International Comparisons of Government R&D Tax Policies

In most OECD countries, government not only provides direct financial support for R&D activities but also uses indirect mechanisms such as tax relief to promote national investment in science and technology. Indeed, tax treatment of R&D in OECD countries is broadly similar, with some variations in the use of R&D tax credits (OECD 1996, 1999a). The following are the main features of the R&D tax instruments:

- Almost all countries (including the United States) allow industry R&D expenditures to be 100 percent deducted from taxable income in the year they are incurred.
- In most countries, R&D expenditures can by carried forward or deducted for 3 to 10 years. (In the United States, there is a 3-year carry-forward on R&D expenditures and a 15-year carry-forward on R&D capital assets.)
- About half the countries (including the United States; see "U.S. Federal and State R&D Tax Credits") provide some type of additional R&D tax credit or incentive, with a trend toward using incremental credits. A few countries also use more targeted approaches, such as those favoring basic research.
- Several countries have special provisions that favor R&D in small and medium-size enterprises. (In the United States, credit provisions do little to help small start-up firms, but more direct Federal R&D support is provided through grants to small firms. See "Federal Support for Small Business R&D.")
- A growing number of R&D tax incentives are being offered at the subnational (provincial and state) levels, including in the United States (see "U.S. Federal and State R&D Tax Credits").[52]

International Public- and Private-Sector R&D and Technology Cooperation

Particularly in light of recent advances in information and communication technologies, international boundaries have become considerably less important in structuring the conduct of R&D and the use of research collaborations. Indicators of R&D globalization illustrate these R&D landscape changes for each of the R&D-performing sectors. Growth in international academic research collaboration is exhibited by the substantial increase in international co-authorship trends. (See chapter 6.) Extensive global growth in public-sector and industrial R&D activities is detailed below.

Public-Sector Collaboration

The rapid rise in international cooperation has spawned activities that now account more than 10 percent of government R&D expenditures in some countries. A significant share of these international efforts results from collaboration in scientific research involving extremely large "megascience" projects. Such developments reflect scientific and budgetary realities: Excellent science is not the domain of any single country, and many scientific problems involve major instrumentation and facility costs that appear much more affordable when cost-sharing arrangements are in place. Additionally, some scientific problems are so complex and geographically expansive that they simply require an international effort.[53] As a result of these concerns and issues, an increasing number of S&T-related international agreements have been forged between the U.S. government and its foreign counterparts during the past decade.

[52]See also Poterba (1997) for a discussion of international elements of corporate R&D tax policies.

U.S. Government's Use of International S&T Agreements

International governmental collaboration in S&T and R&D activities appears to be a growing phenomenon. There are few sources of systematic information on government-to-government cooperative activities, however. A report by the U.S. General Accounting Office (GAO 1999) provides a snapshot of seven Federal agencies' international S&T agreements that were active during FY 1997. The GAO accounting is only for official, formal agreements and therefore provides a lower-bound estimate of the number of governmental global S&T collaborations. Most international cooperation is continuous and ongoing and takes place outside the framework of official, formal agreements. Nonetheless, the GAO study found that these seven agencies—DOE, NASA, NIH, NIST, the National Oceanographic and Atmospheric Administration (NOAA), NSF, and the Department of State—participated in 575 such agreements with 57 countries, 8 international organizations, and 10 groups of organizations or countries. Fifty-four of these agreements were broad-based bilateral arrangements between the U.S. government and governments of foreign countries—commonly referred to as "umbrella" or "framework" agreements. The remaining 521 agreements were bilateral agreements between research agencies and their counterparts in foreign governments and international organizations (381) or multilateral agreements (140) to conduct international cooperative research, provide technical support, or share data or equipment.

Generally, such agreements—which are indicative of government interest to cooperate internationally in R&D—have no associated budget authority. Nor is there a system in place to link international S&T agreements with actual spending on cooperative R&D. According to a study by the Rand Corporation, the U.S. government spent $3.3 billion on R&D projects involving international cooperation in FY 1995 (which may or may not have been associated with international S&T agreements) and an additional $1.5 billion on non-R&D activities associated with international S&T agreements (Wagner 1997).

[53]See OECD (1993 and 1998c) Megascience Forum publications for a concise summary of the history, concepts, and issues behind mega-projects and megascience activities. Additionally, Georghiou (1998) provides a thorough discussion on current global facilities in big science and the emergence of global cooperative programs among governments.

Among the seven agencies that GAO reviewed, DOE participated in the largest number of official international S&T agreements (257, or 45 percent of the 575 total). (See text table 2-17.) This total included almost 100 multilateral agreements with the International Energy Agency (IEA), which represents the United States and 23 other countries with common scientific interests and priorities. NASA was second among the seven agencies in terms of participation in total international S&T agreements (127, including 15 multilateral agreements with the European Space Agency).

In addition to the 140 multilateral agreements, these seven agencies participated in bilateral S&T agreements with countries from almost every region of the world. In terms of the sheer numbers, U.S. agencies were most active in their participation with Japan (78): DOE and NASA reported the largest number of their bilateral S&T agreements with that country. After Japan, U.S. S&T agreements were most commonly reported with Russia (38), China (30), and Canada (25). DOE reported more agreements with Russia and China than did any other agency; NASA accounted for the largest number of agreements with Canada. The prevalence of DOE and NASA in these and other international S&T agreements reflects the megascience attributes associated with their missions. Of the other five agencies in the GAO report, only NIST reported more than five bilateral agreements with any single country (Japan and South Korea) in FY 1997. NIST also listed five agreements with Russia and three with Canada.

Text table 2–17.
Total and bilateral international S&T agreements, by selected agency and country: FY 1997

	Total	Energy	NASA	NIH	NIST	NOAA	NSF	State
Total	575	257	127	44	56	32	26	33
Multilateral	140	107	15	1	7	7	3	0
Bilateral[a]	435	150	112	43	49	25	23	33
Asia	151	56	31	13	24	10	10	7
Japan	78	28	26	4	13	2	4	1
China	30	20	0	3	1	2	3	1
Korea	20	7	0	2	7	1	2	1
Other	23	1	5	4	3	5	1	4
Europe	150	48	37	16	11	7	13	18
Russia	38	16	8	4	5	1	3	1
France	21	9	6	1	0	4	1	0
Germany	15	1	8	3	0	0	3	0
United Kingdom.	11	5	3	1	0	1	1	0
Italy.	11	2	4	3	1	0	0	1
Other.	54	15	8	4	5	1	5	16
South & Central America	48	22	13	2	6	1	0	4
Venezuela	15	12	0	1	1	0	0	1
Brazil	12	3	6	0	1	1	0	1
Argentina	10	3	4	0	2	0	0	1
Chile	8	2	3	1	1	0	0	1
Other	3	2	0	0	1	0	0	0
North America	34	8	14	4	4	3	0	1
Canada	25	5	14	1	3	2	0	0
Mexico	9	3	0	3	1	1	0	1
South Pacific	24	8	11	2	1	1	0	1
Australia	16	5	9	1	0	1	0	0
Other	8	3	2	1	1	0	0	1
Africa	15	6	2	2	2	1	0	2
South Africa	9	3	2	1	1	1	0	1
Other	6	3	0	1	1	0	0	1
Middle East	13	2	4	4	1	2	0	0
Israel	8	1	4	3	0	0	0	0
Other	5	1	0	1	1	2	0	0

NOTES: These are official international science and technology agreements only. Bilateral agreements between the Department of State and other countries are broad government-level agreements. In some cases, they provide the formal framework for establishing bilateral agreements detailed in the table. The GAO source report included Russia in its Asia counts; Russia is included here in the Europe totals.

[a] Country counts include bilateral agreements only.

SOURCE: Government Accounting Office. 1999. *Federal Research: Information on International Science and Technology Agreements.* GAO/RCED – 99-108. Washington, DC: GAO.

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Overall, more than 90 percent of the international S&T agreements active in FY 1997 resulted in research projects or other research-related activities. In cases in which this activity did not occur, funding problems that developed after the agreements were signed or changes in research priorities generally were the reasons for their discontinuation.

International S&T collaboration can and does increasingly take place under less formal agreements, however. Consequently, these measures of formal agreements do not necessarily represent the level or intensity of R&D relationships or international collaboration between scientific communities in various countries.[54]

Private-Sector Collaboration

International R&D collaboration is on the rise in the private sector as well—as is indicated by the rising number of formal cooperative agreements or alliances between firms, the growth of overseas R&D activities performed under contract and through subsidiaries, and an increase in the number of R&D laboratories located abroad (OECD 1998a). The expansion of international industrial R&D activity appears to be a response to the same competitive factors that foster domestic collaborations. Firms reach beyond their home borders as a way of addressing rising R&D costs and risks in product development, shortened product life cycles, increasing multidisciplinary complexity of technologies, and intense competition in domestic and global markets.

International Strategic Technology Alliances

Historical Trends

Industrial firms increasingly have used global research partnerships to strengthen their core competencies and expand into technology fields they consider critical for maintaining market share. In these partnerships, organizations can expand opportunities and share risks in emerging technologies and emerging markets. During the first half of the 1970s, strategic alliances were almost nonexistent, but they expanded rapidly late in the decade. For example, the number of newly made partnerships in the three core technologies—information technologies, biotechnology, and new materials—rose from about 10 alliances created in 1970 (Hagedoorn 1996) to about 90 in 1980. R&D-related international strategic technology alliances increased sharply throughout the industrialized world in the early 1980s and accelerated as the decade continued, reaching 580 such partnerships in 1989.[55] In the early 1990s, the annual formation of newly established alliances at first tapered off from that reported in the 1980s and then rapidly increased to a peak of more than 800 new alliances formed in 1995. Since then, there has been a steady decrease in the number formed, to 564 in 1998—a total that nonetheless exceeds the number formed during any year prior to 1989. For the entire 1980–98 period, U.S., European and Japanese firms collectively entered into almost 9,000 strategic technology alliances. Most of these alliances were formed in the 1990s; most involved U.S. firms; and most were signed to foster R&D partnerships in just a few high-tech areas, notably information technologies and biotechnology. (See figure 2-36, text table 2-18, and appendix table 2-67.)

As the number of alliances has increased, the forms of cooperative activity have changed as well. The most prevalent modes of global industrial R&D cooperation in the 1970s were joint ventures and research corporations. In these arrangements, at least two companies share equity investments to form a separate and distinct company; profits and losses are shared according to the equity investment.[56] In the second half of the 1980s and into the 1990s, joint nonequity R&D agreements became the most common form of partnership. Under such agreements, two or more companies organize joint R&D activities to reduce costs and minimize risk while they pursue similar innovations; participants share technologies but have no joint equity linkages (Hagedoorn 1990, 1996).

Country Focus

Between 1990 and 1998, more than 5,100 strategic technology alliances were formed, of which 2,700 were intraregional (that is, made between firms located within the broad regions of Europe, Japan, or the United States) and 2,400 were interregional (between firms located in separate regions). Of course, many of the more than 500 intra-European alliances are also multinational because they generally involve firms from more than one European country (in contrast with the numerous intra-American and much less numerous intra-Japanese firm partnerships in which all partners have the same national ownership). For the 1990–98 period, U.S. companies participated in 80 percent of known technology alliances, about half of which were between two or more U.S. firms and about half of which included a non-U.S. company. European companies participated in 42 percent and Japanese companies in 15 percent of the 5,100 alliances formed in the 1990s. (See text table 2-18).

Consistent with overseas R&D funding trends (detailed below), just a handful of European firms account for most of that region's alliances. Of the 4,700 European alliances re-

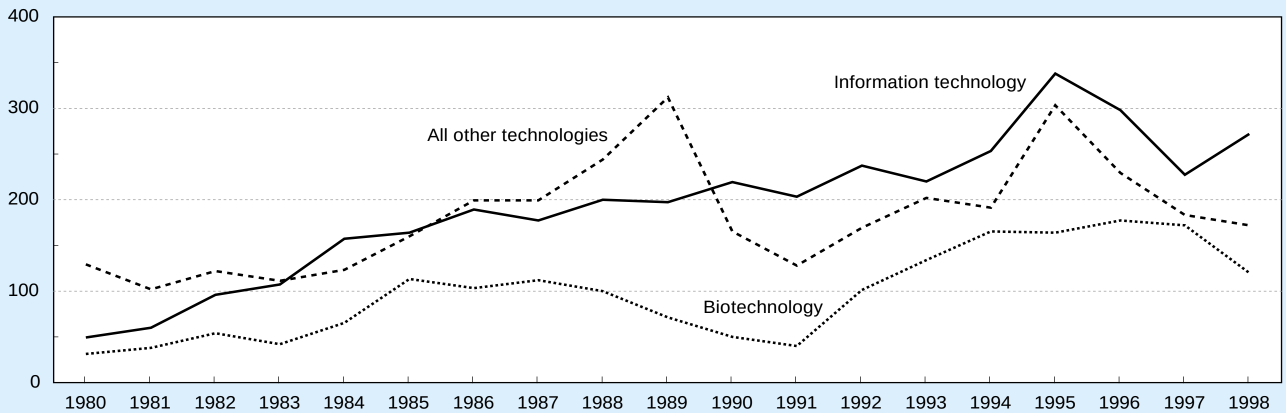
[54]See chapter 6 for information on patterns of international co-authorship.

[55]Information in this section is drawn from an extensive database compiled in the Netherlands— the Maastricht Economic Research Institute on Innovation and Technology's (MERIT 1999) Cooperative Agreements and Technology Indicators (CATI) database—on literally thousands of inter-firm cooperative agreements. The CATI database collects only agreements that contain arrangements for transferring technology or joint research. These counts are restricted to strategic technology alliances, such as joint ventures for which R&D or technology sharing is a major objective; research corporations; and joint R&D pacts. The historical totals reported here differ from those reported in previous *Science & Engineering Indicators*. Previously, alliances of minority holdings coupled with research contracts were included in the totals. Here such alliances are not included in the totals.

CATI is a literature-based database: Its key sources are newspapers, journal articles, books, and specialized journals that report on business events. Its main limitations are that data are limited to activities publicized by the firm, agreements involving small firms and certain technology fields are likely to be underrepresented, reports in the popular press are likely to be incomplete, and it probably reflects a bias because it draws primarily from English-language materials. CATI information should therefore be viewed as indicative and not comprehensive.

[56]Joint ventures are companies that have shared R&D as a specific company objective, in addition to production, marketing, and sales. Research corporations are joint R&D ventures with distinctive research programs.

Figure 2-36.
New international strategic technology alliances, by technology



NOTE: Includes alliances of firms located both within broad regions and across broad regions.

See appendix table 2-67.

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ported during the entire 1980–98 period (a figure that includes double-counting of partnerships with two or more European firms), the most active participants were British firms (1,036 alliances), German firms (994), French firms (715) and Dutch firms (680). More than 100 alliances were also formed by companies with Italian (338), Swiss (267), Swedish (278), and Belgian (119) ownership. Additionally, a substantial number of the international technology partnerships involved firms located outside of these major regions. During the entire 1980–98 period, Canadian firms entered into 198 strategic technology alliances (mostly with U.S. companies), South Korean firms joined 119, Russian (and other former Soviet Union) firms joined 90,[57] Chinese firms joined 86, Australian firms joined 63, Israeli firms joined 51, and Taiwanese firms joined 48.

Technology Focus

Most intraregional and interregional alliances have been between firms sharing research and technology development in information technologies (IT) and biotechnology. These two technologies alone account for two-thirds of all alliances formed since 1990. The only other technologies for which firms consistently have entered into a substantial number of partnerships relate to advanced materials and non–biotechnology-based chemicals. (See appendix table 2-67.) Forty-four percent of the technology alliances formed worldwide since 1990 dealt with information technologies such as computer software and hardware, telecommunications, industrial automation, and microelectronics. Of the roughly 2,300 IT alliances formed during this period, most have been between U.S. companies (50 percent) or between European and U.S. firms (19 percent). Among the 1,100 strategic biotechnology alliances, the regional distribution has been more diverse, although U.S.-U.S. and U.S.-European interregional partnerships are more prevalent than any other (each type accounting for more than one-third of the biotechnology total). Consistent with R&D funding trends and indicative of known core strengths, U.S.-Japanese collaborations are more common in IT activities than in biotechnology.

International Industrial R&D Investment Growth

Stiff international competition in research-intensive, high-technology products and market opportunities have compelled firms throughout the world to expand their overseas research activities. Foreign sources account for a growing share of domestic R&D investment totals in many countries. (See figure 2-32.) Many firms have R&D sites in countries outside their home base. Although the data are somewhat scant, the share of R&D performed by foreign affiliates appears to have risen perceptibly throughout the OECD during the past two decades (OECD 1998a). Currently, the share of R&D performed by foreign affiliates accounts on average for 14 percent of the industrial R&D performed in OECD countries. This share varies considerably among hosting countries, however—from a low of 1 percent in Japan to a high of 68 percent in Ireland (OECD 1999d).

Although many factors contribute to a business decision to locate R&D capabilities outside a firm's home country, the basic drivers fall into demand-side and supply-side considerations.

Multinational firms seek a foreign R&D presence to support their overseas manufacturing facilities or to adapt standard products to the demand there. R&D facilities are established to customize existing products or to develop new

[57]See Hagedoorn and Sedaitis (1998) for summary data on international strategic technology alliances between Western companies and Russian companies.

Text table 2–18.
Strategic Technology Alliances, by region: 1980–98

	Total alliances	Information technology	Biotechnology	All other technologies
1980–1989 alliances				
Total	3,826	1,396	729	1,701
USA-Europe	809	296	152	361
USA-Japan	550	209	93	248
USA-Others	178	44	23	111
Europe-Japan	237	84	24	129
Europe-Others	188	55	15	118
Japan-Others	53	8	8	37
Intra-USA	908	400	247	261
Intra-Europe	670	242	125	303
Intra-Japan	233	58	42	133
Percent of 1980–1989 totals				
Total	100.0	100.0	100.0	100.0
USA-Europe	21.1	21.2	20.9	21.2
USA-Japan	14.4	15.0	12.8	14.6
USA-Others	4.7	3.2	3.2	6.5
Europe-Japan	6.2	6.0	3.3	7.6
Europe-Others	4.9	3.9	2.1	6.9
Japan-Others	1.4	0.6	1.1	2.2
Intra-USA	23.7	28.7	33.9	15.3
Intra-Europe	17.5	17.3	17.1	17.8
Intra-Japan	6.1	4.2	5.8	7.8
1990–1998 alliances				
Total	5,132	2,267	1,123	1,742
USA-Europe	1,284	434	403	447
USA-Japan	437	259	66	112
USA-Others	254	113	44	97
Europe-Japan	195	75	32	88
Europe-Others	174	50	33	91
Japan-Others	40	22	5	13
Intra-USA	2,150	1,140	436	574
Intra-Europe	521	142	100	279
Intra-Japan	77	32	4	41
Percent of 1990–1998 totals				
Total	100.0	100.0	100.0	100.0
USA-Europe	25.0	19.1	35.9	25.7
USA-Japan	8.5	11.4	5.9	6.4
USA-Others	4.9	5.0	3.9	5.6
Europe-Japan	3.8	3.3	2.8	5.1
Europe-Others	3.4	2.2	2.9	5.2
Japan-Others	0.8	1.0	0.4	0.7
Intra-USA	41.9	50.3	38.8	33.0
Intra-Europe	10.2	6.3	8.9	16.0
Intra-Japan	1.5	1.4	0.4	2.4

See appendix table 2-67. *Science & Engineering Indicators – 2000*

products for the local market. Additionally, such facilities may provide technical service support to local manufacturing activities as their primary purpose. In some situations, however, the location of R&D facilities is the price of entry to the local market. These arrangements constitute a home-base exploiting site, where information tends to flow to the foreign laboratory from the central home laboratory.

Conversely—and more commonly of late—the foreign site is established to tap knowledge and skilled labor from competitors and universities around the globe, including the direct employment of local talents; to participate in joint research ventures and cooperative agreements; and to passively monitor technological development abroad. These facilities have the characteristics of a home-base augmenting site, where information tends to flow from the foreign laboratory to the central home laboratory. Generally, however, there is little evidence to suggest that firms go abroad to compensate for their R&D weaknesses at home. Rather, they locate in foreign centers of excellence to supplement their existing core strengths (Patel and Vega 1999).

According to a study of 238 foreign R&D sites, 45 percent of the labs were home-base augmenting and 55 percent were home-base exploiting (Kuemmerle 1997).[58]

U.S. and Foreign Industrial R&D Expenditure Balance

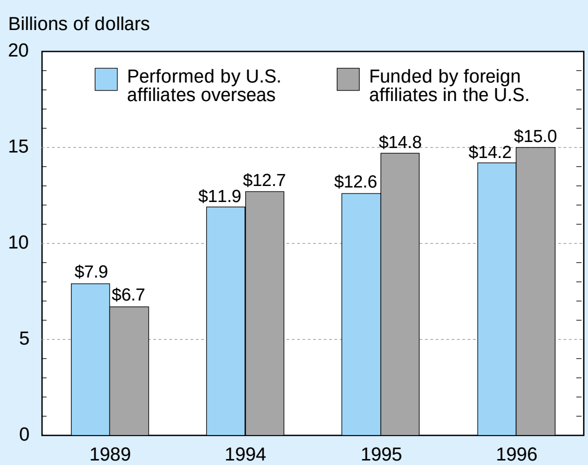
U.S. companies' R&D investments abroad are roughly equivalent to R&D expenditures in the United States by majority-owned U.S. affiliates of foreign companies.[59] In 1996 (the latest year for which complete data from the Bureau of Economic Analysis [BEA] are available at this writing), industrial R&D flows into the United States totaled $15.0 billion, compared with $14.2 billion in R&D expenditures by U.S. multinational firms in other countries. (See figure 2-37.) This approximate balance in R&D investment flows has persisted since (at least) 1989, when the majority-owned data first became available on an annual basis. In 1989, however, U.S. companies conducted a greater amount of R&D abroad than was invested in the United States by foreign firms. The reverse now appears to be true: More industrial R&D money is flowing into the United States than U.S. firms are performing abroad. Whatever the exact "balance" in any given year, however, higher levels of U.S. R&D investment in foreign economies and non-U.S. R&D investment within the U.S. domestic economy clearly are becoming the norm (Mowery 1998a).

Europe is the primary source and the main location of performance of these U.S.-foreign industrial R&D flows. (See figure 2-38.) European firms invested $11.2 billion of R&D money in the United States in 1996; the Asian (excluding the Middle East) and Pacific region provided the second largest source of foreign R&D funds ($1.9 billion). Similarly, foreign affiliates of U.S. companies performed $9.7 billion of R&D in Europe and $2.1 billion in Asia and the Pacific region.[60] Industrial R&D investments between Canada and the United States are in the $1.5 billion range. U.S. industry's R&D flows remain relatively small (less than $1 billion) into and out of Latin America and the Middle East and are negligible with Africa.

[58]The terms "home-base exploiting" and "home-base augmenting" are taken directly from Kuemmerle (1997). Others, however (e.g., Mowery 1998b and Dalton, Serapio, and Yoshida 1999), have made similar observations on the reasons for expanding global R&D arrangements. Furthermore, Mowery notes that the use of international R&D strategies to establish networks for the creation and strengthening of firm-specific technological capabilities (i.e., home-base augmenting) is likely to become more important than market exploitation-driven activities in the future.

[59]These overseas R&D data are from the BEA survey on U.S. Direct Investment Abroad. The definition used by BEA for R&D expenditures is from the Financial Accounting Standards Board Statement No. 2; these expenditures include all charges for R&D performed for the benefit of the affiliate by the affiliate itself and by others on contract. BEA detail is available for 1982 and annually since 1989. Data on foreign sources of industrial R&D performed in the United States come from an annual survey of Foreign Direct Investment in the United States, also conducted by BEA. BEA reports that foreign R&D totals are comparable with U.S. R&D business data published by NSF. Industry-specific comparisons, however, are limited because of differences in the industry classifications used by the two surveys (Quijano 1990).

Figure 2-37.
Globalization of U.S. industrial R&D



NOTE: Data for majority-owned (50 percent or more) non-bank affiliates only.

See appendix tables 2-69 and 2-71.

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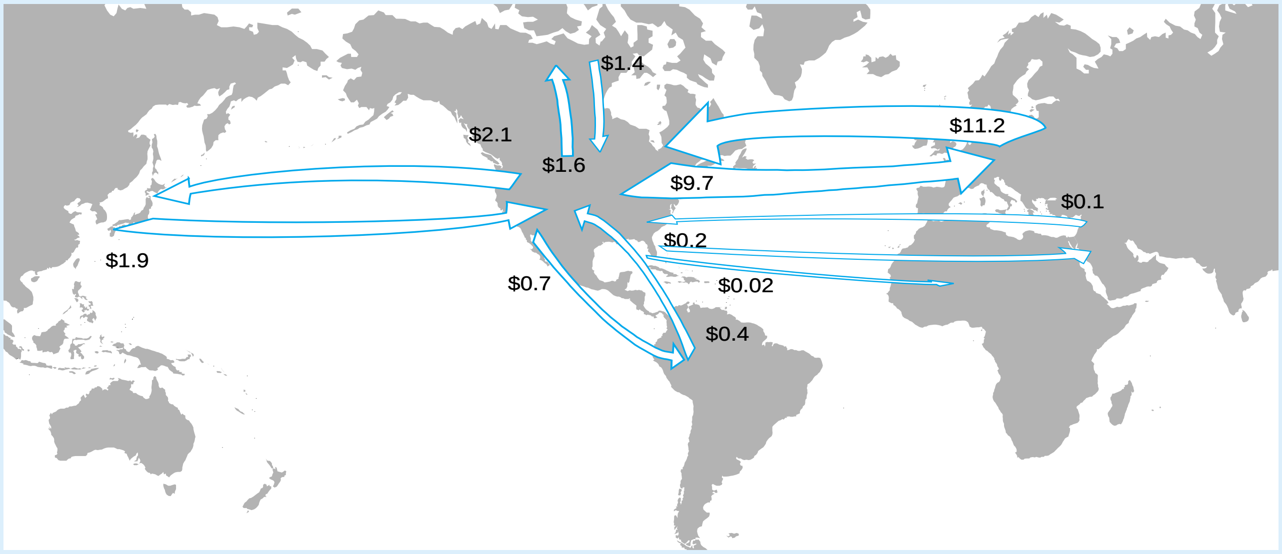
Trends in U.S. Industry's Overseas R&D

From 1985 through 1996, U.S. firms generally increased their annual funding of R&D performed outside the country more than their funding of R&D performed in the United States. (See appendix table 2-68.) Indeed, during this period U.S. firms' investment in overseas R&D increased 2.8 times faster than did company-funded R&D performed domestically (9.7 percent versus 3.4 percent inflation-adjusted average annual growth). Overseas R&D funding accounted for about 6.0 percent of U.S. industry's total (domestic plus overseas) R&D funding in 1985; in 1996 overseas R&D accounted for 10.4 percent of U.S. industry's total R&D. In 1997, however, strong growth in U.S. companies' domestic R&D financing (up 10 percent), coupled with a 7 percent decline in

[60]Analyses of the BEA data on overseas R&D activities of U.S. affiliates have become complicated as a result of a change in survey collection. Prior to the 1994 survey, BEA collected expenditure data on R&D funding by U.S. overseas affiliates regardless of whether the R&D was performed by the affiliate of by others. It excluded R&D conducted by the affiliate under contract for others. Beginning with the 1995 survey, U.S. affiliates were asked to report their R&D performance irrespective of the funding sources (i.e., they report R&D conducted in their own labs, including R&D funded by the affiliate itself and by others under contracts). R&D funded by the U.S. affiliate but conducted by other organizations are excluded. Consequently, the more recent BEA figures represent R&D performance of U.S. firms' foreign affiliates and not the foreign R&D funding made by U.S. firms.

Figure 2-38.
Industrial R&D of U.S. and foreign affiliates, by world region: 1996

Billions of dollars



See appendix tables 2-69 and 2-71. *Science & Engineering Indicators – 2000*

industry's overseas R&D spending, reduced the overseas share to 8.9 percent of U.S. companies' funding total.[61]

Additionally, according to BEA data, the majority-owned (that is, 50 percent or more) foreign-affiliate share of U.S. multinational companies' worldwide R&D expenditures increased from 9 percent in 1982 to 13 percent in 1990, where it remained through 1994 (Mataloni and Fahim-Nader 1996). According to preliminary data for 1996, the foreign-affiliate share of U.S. multinationals' total R&D funding rose to 14 percent (Mataloni 1998).

Sector Focus of Overseas R&D Activity

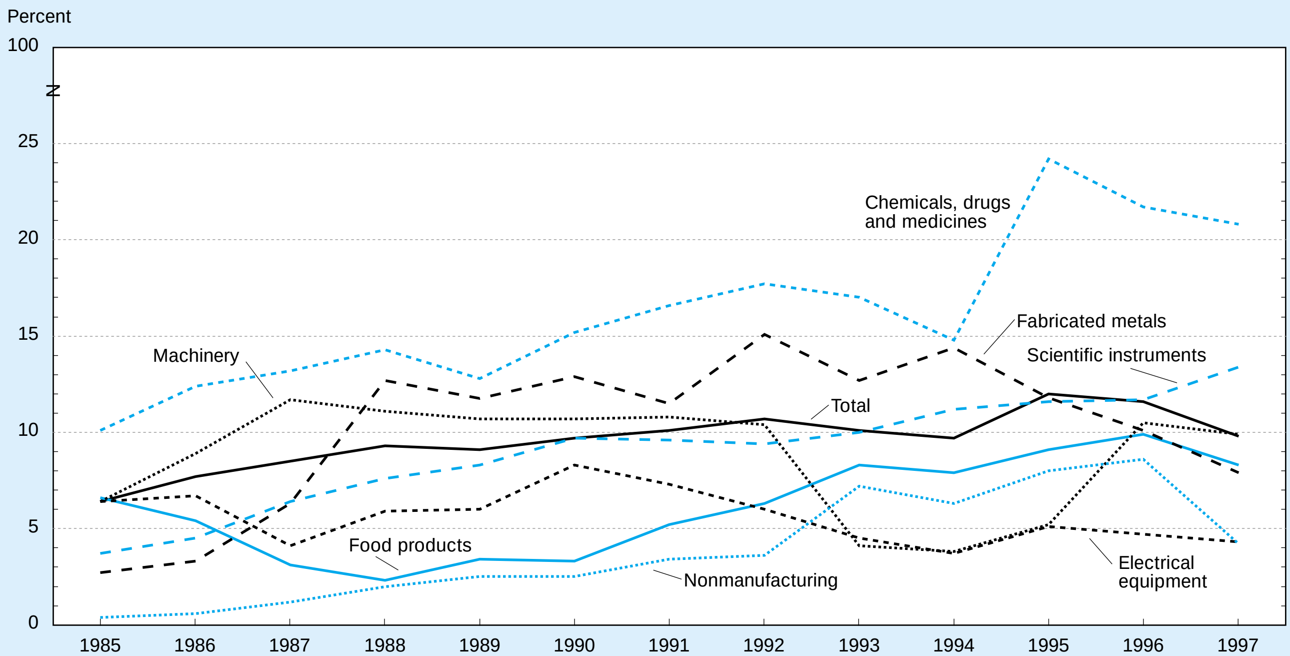
R&D investment by U.S. companies and their foreign subsidiaries in the chemicals (including pharmaceuticals and industrial chemicals) industry accounts for the largest share and greatest growth of foreign-based R&D activity. (See figure 2-39.) Indeed, drug companies accounted for 18 percent of total 1997 overseas R&D ($2.4 billion of the $13.1 billion total)—equivalent to 21 percent of the pharmaceutical industry's domestically financed R&D. Part of this growth undoubtedly is a function of the worldwide pattern of collaboration between integrated global pharmaceutical firms and emerging biotechnology companies in the U.S. and Europe—most notably the United Kingdom (Council on Competitiveness 1998). (See appendix table 2-68.)

Similarly, firms in the industrial and other chemicals industry spent an amount overseas ($1.5 billion) equivalent to 21 percent of their onshore R&D investment. Demand and supply factors alike seem to be driving this internationalization. R&D is performed overseas so that global firms are better able to customize their products to meet the needs of local customers and to ensure market access. Furthermore, chemicals R&D performance is becoming global because different regions of the world are becoming technologically specialized—Germany, for example, in fundamental research in organic synthesis and Japan in electronic chemicals (Arora and Gambardella 1999). Of other major R&D-performing manufacturers, recent trends show the overseas R&D investment share of total R&D financing rising considerably for scientific instruments ($1.2 billion in 1997, equivalent to 13 percent of the domestic total) and machinery equipment ($1.8 billion in 1997, equivalent to 10 percent of the domestic total).

Growth in overseas R&D investments is not limited to sectors with strong historical experience in overseas production activity. The combined total for all nonmanufacturing industries indicates substantial increases in foreign R&D activity since 1985—rising from 0.4 percent of domestic R&D funding that year to 8.6 percent in 1996. Part of this growth reflects increased international R&D financing by firms historically classified as nonmanufacturing industries

[61]These overseas R&D shares are taken from the NSF industrial R&D data series, not the BEA Direct Investment Abroad series used in the "U.S. and Foreign Industrial R&D Expenditure Balance" discussion. However, BEA data on the country destination of the U.S. overseas R&D investment are more complete than the NSF series and therefore are used to describe country patterns. NSF reports 1996 and 1997 overseas R&D totals of $14.1 billion and $13.1 billion, respectively; BEA estimates 1996 overseas R&D performance by foreign affiliates of U.S. companies (including both for the affiliate and for others) at $14.2 billion.

Figure 2-39.
Ratio of U.S. overseas R&D to company-financed domestic R&D



See appendix table 2-68. *Science & Engineering Indicators – 2000*

(particularly computer, data processing, and architectural services). Part of the increase reflects the movement of firms previously classified as manufacturers (e.g., office computing companies) to service sector industries (e.g., software development). This observation is borne out by the reduction in nonmanufacturers' overseas R&D in 1997 ($1.4 billion, down from $2.5 billion in 1996). Most of this decline reflects firms' shifting industry classifications within IT-related industries rather than an actual drop in industrial funding activity. Nonetheless, overseas R&D investments in information technologies remain substantial. One factor driving such globalization is that foreign labor markets provide U.S. companies with an ample supply of qualified (and sometimes less-expensive) science and engineering personnel—as indicated by robust IT investments in English-speaking India, Ireland, and Canada.[62] (See chapter 3 on the Science and Engineering Workforce and chapter 9 on the Significance of Information Technologies.)

Country Location of U.S. Overseas R&D Activity

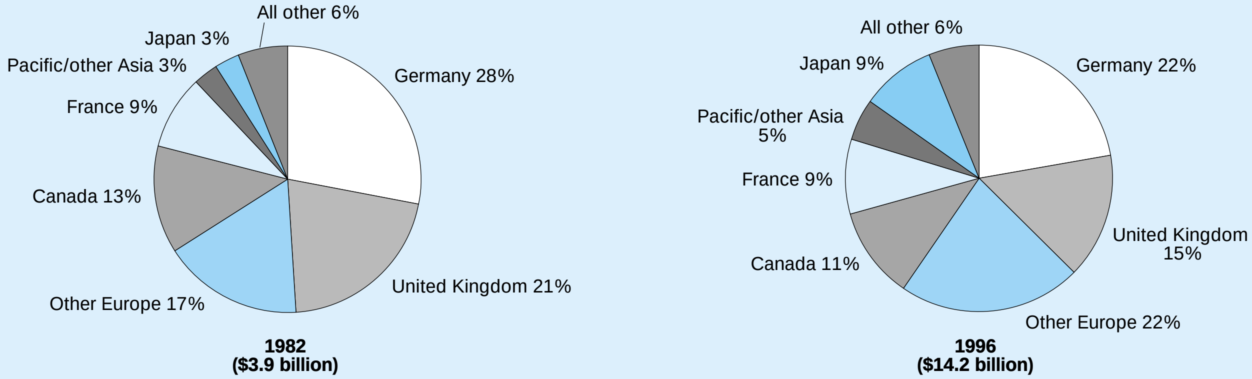
As BEA data on majority-owned foreign affiliates of nonbank U.S. multinational companies indicate, most of the U.S. 1996 overseas R&D was performed in Europe—primarily Germany (22 percent of the U.S. overseas total), the United Kingdom (15 percent), and France (9 percent). (See figure 2-40 and appendix table 2-69.) Collectively, however, the current 68 percent European share of the U.S. total R&D investment abroad is less than the 75 percent share reported for 1982. Since the early 1980s, U.S. R&D investments abroad have generally shifted from the larger European countries and Canada toward Japan, several of the smaller European countries (notably Sweden and the Netherlands), Australia, and Brazil.

As indicated by affiliate industry classifications, U.S. R&D investments abroad are concentrated in specific geographic locations. Almost half of the offshore automotive R&D in 1996 was spent in Germany; spending by transportation equipment companies accounted for almost two-thirds of all U.S. affiliate R&D activity in Germany. In the United Kingdom, France, Japan, and Italy, the chemicals industry accounted for the largest share of each country's respective R&D totals; collectively these four countries accounted for 54 percent of all U.S. affiliates' chemicals-related R&D. Electrical equipment firms accounted for most of the U.S. affiliates' R&D performance in the Netherlands; except for Germany, no other country accounted for more of the U.S. affiliates' electrical equipment R&D than did this relatively small country. (See text table 2-19.) These industry R&D emphases reflect the general industrial strengths of the various countries.

After Germany ($3.1 billion) and the United Kingdom ($2.1 billion), Canada is the next-largest site of U.S. overseas R&D performance. Almost $1.6 billion was spent in major-

[62]For an informative discussion on the internationalization of R&D in Canada, see Anderson and Gault (1999). The information and communications sector now appears to account for 69 percent of the total foreign R&D funding provided Canada's industrial sector.

Figure 2-40.
U.S. R&D performed abroad



See appendix table 2-69.

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Text table 2–19.
R&D performed overseas by majority-owned foreign affiliates of U.S. parent companies, by selected country and industry of affiliate: 1996 (millions of U.S. dollars)

Country	All industries	Manufacturing					Nonmanu-facturing
		Total	Chemicals	Machinery	Electrical equipment	Transportation equipment	
Total	14,181	12,358	3,700	1,063	1,258	4,252	1,823
Canada	1,582	1,457	302	28	97	D	125
Europe	9,651	8,625	2,715	746	749	2,894	1,026
Belgium	369	299	197	3	3	33	70
France	1,326	1,169	658	85	47	90	157
Germany	3,061	2,916	279	234	209	1,939	145
Italy	553	D	267	59	54	57	D
Netherlands	545	382	101	9	149	17	163
Spain	317	298	75	5	34	D	19
Sweden	439	404	D	22	9	*	35
Switzerland	189	134	29	D	D	–	55
United Kingdom	2,133	1,860	682	262	69	D	273
Rest of Europe	719	D	427	67	D	D	D
Asia and Pacific	2,073	1,582	552	262	220	D	491
Australia	409	318	85	D	1	D	91
Japan	1,337	1,002	405	184	132	2	335
Rest of Asia/Pacific	327	262	62	D	87	D	65
Western hemisphere	687	647	106	15	189	276	40
Brazil	489	482	61	10	D	D	7
Mexico	119	100	17	5	D	D	19
Middle East (Israel)	166	28	13	10	3	0	138
Africa	21	19	12	3	*	0	2

D = withheld to avoid disclosing operations of individual companies; * = less than $500,000

NOTES: Includes direct investments of majority-owned nonbank foreign affiliates of U.S. parents. Includes R&D expenditures conducted by the foreign affiliates for itself or for others under a contract.

SOURCE: U.S. Bureau of Economic Analysis, U.S Direct Investment Abroad (Washington, DC: BEA, 1998)

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ity-owned Canadian affiliates of U.S. firms. These considerable R&D investments are consistent with the overall facts that these two countries are one another's most important trade partners and that the level of U.S. investment in Canada is among the highest anywhere in the world. Unfortunately, disclosure restrictions to protect the confidentiality of specific firms' underlying R&D expenditures limit the amount of publishable data about the industries in which this considerable U.S. investment is being made.

Industry-wide, nonmanufacturing industries (including business services, with $0.9 billion) now account for 13 percent ($1.8 billion) of U.S. overseas R&D performance. Of this amount, majority-owned Japanese affiliates of U.S. multinational firms accounted for the largest single country share. (See text table 2-19.)

U.S. Industry's Overseas R&D Facilities

The U.S. Department of Commerce recently compiled data on R&D facilities located abroad (Dalton, Serapio, and Yoshida 1999). Although the information is based largely on secondary sources and is at best a sample of such activities, it nonetheless is illustrative of patterns in the establishment of U.S. R&D facilities overseas. There were 186 known foreign R&D facilities owned by 85 U.S. companies in 22 countries in 1997.

The list of U.S. facilities by country is similar to the list of countries in which U.S. firms spend the largest amounts of R&D investments abroad. Japan leads all countries as the site of U.S. R&D facilities (43), followed by the United Kingdom, Canada, France and Germany. As with foreign-owned facilities located in the United States (see "U.S. Research Facilities of Foreign Firms"), the largest number of U.S.-owned foreign facilities support the automotive (32 facilities), drugs and biotechnology (28), computers (25), and chemicals and rubber (23) industries. Although the data are not conclusive, U.S. firms have chosen to locate facilities in Japan to serve a variety of chemicals, drugs, automotive, and computer R&D needs. (See text table 2-20.)

The mix of industries represented by facility sites in major host countries is quite diverse.[63] For example, in the automotive and drug/biotechnology industries, U.S. firms own three or more facilities in five or more countries. Additionally, several emerging countries have been chosen as important locations for U.S. firms' R&D facilities. The most notable examples are Singapore (which now hosts 13 U.S.-owned facilities), Taiwan, and India—each of which has attracted relatively high levels of foreign R&D and created high-technology centers in their countries. Although China and Russia have been mentioned as potential future sites for U.S. R&D investments, protection of intellectual property remains a major concern that may limit such growth.

Motives for establishing overseas R&D facilities are manifold and differ among industries; technology or supply-oriented reasons have increasingly influenced the decision of U.S. firms to locate R&D abroad (a home-base augmenting strategy). This trend is particularly true for electronics and computer software. Even when companies initially invested abroad for the purpose of assisting their manufacturing/sales/service facilities in a local market (a home-base exploiting strategy), they increasingly are positioning these R&D facilities as regional R&D bases (Dalton, Serapio, and Yoshida 1999).

[63]The figures in text table 2-20 represent only counts of facilities, however. The facilities themselves differ considerably in terms of dollars spent and scientists and engineers employed. More detailed information about the individual sites would permit a clearer determination of industry clustering and decentralization.

Text table 2–20.
U.S. R&D facilities abroad: 1997

Industry	Japan	United Kingdom	Canada	France	Germany	Others
Total	43	27	26	16	15	55
Automotive	6	4	4	4	5	9
Computers	7	5	0	1	2	10
Software	4	1	1	0	0	6
Semiconductors	4	1	0	1	0	6
Opto-electronics, telecom	2	0	2	2	1	6
Other electronics	3	2	2	1	1	2
Drugs, biotechnology	8	5	4	3	3	5
Chemicals, rubber	9	1	2	2	2	7
Other transportation equip	0	0	3	0	0	0
Metals, petroleum refining	0	2	6	0	0	6
Instrumentation, medical devices	0	5	3	0	0	2
Food, consumer goods, misc	1	3	4	2	0	5

NOTE: "Other countries" include 13 facilities in Singapore, 11 in China, and 8 in Belgium. These data are derived from secondary sources and are therefore a sample of the total (unknown) number of R&D facilities. The industry-specific detail may double-count some facilities because of the multiple focus of research performed. Not all industry categories are listed. The country totals do not include double-counting.

SOURCE: U.S. Department of Commerce, *Globalizing Industrial Research and Development*, by D. H. Dalton and M. G. Serapio, and P.G. Yoshida. Washington, DC, 1999.

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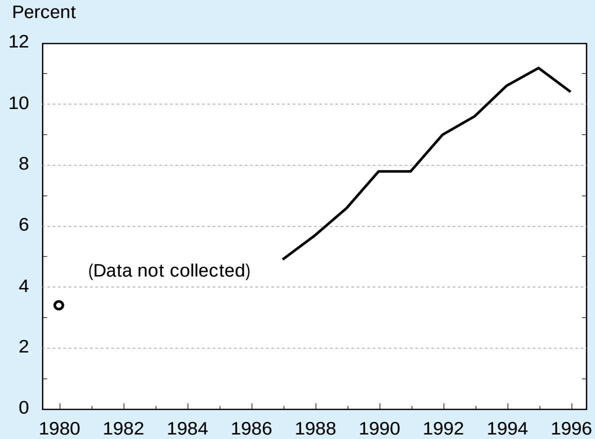
Foreign R&D in the United States

Like U.S. firms' overseas R&D funding trends, R&D activity by foreign-owned companies in the United States has increased significantly since the mid-1980s. From 1987 to 1996, inflation-adjusted R&D growth from foreign firms (U.S. affiliates with a foreign parent that owns 50 percent or more of the voting equity) averaged 10.9 percent per year. (See appendix table 2-71).[64] This growth contrasts favorably with the 3.9 percent average annual rate of real increase in U.S. firms' domestic R&D funding. It also is almost six times the 1.3 percent 1987–96 growth rate of total domestic industrial R&D performance (including activities funded by foreign firms and the Federal Government). As a result of these funding trends, foreign R&D was equivalent to 10.4 percent ($15 billion) of total industrial R&D performance in the United States in 1996. This share is more than double that of its equivalent 4.9 percent share in 1987 but slightly lower than the calculated 1995 estimate (11.2 percent). Majority-owned affiliates accounted for a 3.4 percent share of the U.S. 1980 industrial performance total. (See figure 2-41.)

Figure 2-41.
U.S. industrial R&D financed by majority-owned foreign firms



NOTE: Data are available for 1980, and for 1987 and later years. See appendix tables 2-3 and 2-71.

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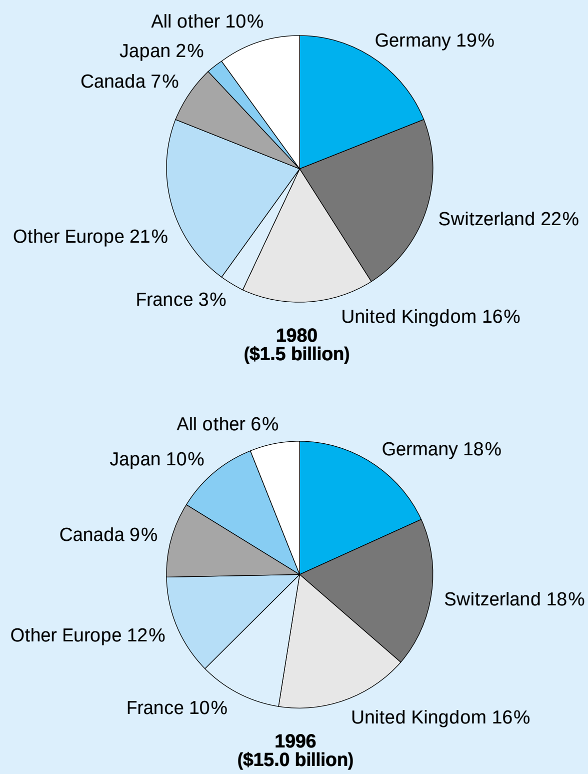
Country Sources of Industrial R&D

Most R&D financed by foreign affiliates in the United States comes from firms whose parents are located in just three countries: Germany, Switzerland, and the United Kingdom. Indeed, 81 percent of foreign R&D funding in 1996 came from just six countries—those three countries, plus France, Japan, and Canada. (See figure 2-42.) With the exception of Switzerland, these six countries are the same as those that receive the largest shares of U.S. overseas R&D investments. (Italy replaces Switzerland in that listing). Thus, the globalization of R&D is characterized by significant two-way flows of cross-border activities.

Looking beyond these major R&D country centers, however, the geographic pattern of R&D flows into the United States differs from the trends for U.S. R&D spending abroad. Whereas countries other than G-7 countries (and Switzerland) have become increasingly important as destinations for U.S. funding, they are becoming relatively less important in terms of foreign R&D investments here. For example, in 1980, firms from the six countries listed above accounted for a 69 percent share of the foreign R&D flows into the United States—a considerably smaller share than they currently account for. By contrast, those six countries accounted for 76 percent of

Figure 2-42.
U.S. industrial R&D financed by majority-owned foreign firms



See appendix table 2-71. *Science & Engineering Indicators – 2000*

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[64]Although BEA considers all of an investment (including R&D) to be foreign if 10 percent or more of the investing U.S.-incorporated firm is foreign-owned, special tabulations were prepared by BEA to reveal R&D expenditures in the United States of firms in which there is majority foreign ownership (i.e., 50 percent or more). For 1996, the 10 percent foreign ownership threshold results in an estimated $17.2 billion foreign R&D investment total. (See appendix table 2-70.) R&D expenditures of majority-owned U.S. affiliates of foreign companies were $15.0 billion. (See appendix table 2-71.) Tabulations for the majority-owned firms' R&D financing are used for most of the analyses here; the sole exception is the use of foreign R&D data at the 10 percent threshold for review of country-specific funding patterns for individual industrial sectors. (See text table 2-21.) Such data for majority-owned affiliates are not available.

U.S. overseas R&D in 1982 but only 68 percent in 1996. At least part of the increase in R&D flows from Canada and other European countries over the past 15 years is attributable to several major acquisitions of U.S. firms by foreign multinational companies. Such acquisitions have been particularly instrumental in changing the foreign composition shares of U.S. pharmaceutical and biotechnology firms with large R&D budgets (Dalton, Serapio, and Yoshida 1999; Fahim-Nader and Zeile 1998).

Industry Focus of Foreign R&D

Foreign-funded research was concentrated in three industries in 1996: drugs and medicines (mostly from Swiss, German, and British firms), industrial chemicals (funded predominantly by German and Dutch firms), and electrical equipment (one-third of which came from French affiliates).[65] These three industries accounted for more than half of the $17.2 billion total 1996 foreign R&D investment by affiliates in which there was at least 10 percent foreign ownership. Concurrent with gains reported for all domestic U.S. R&D performance, foreign—particularly Japanese and Swiss—R&D investment in the service sector was also significant. Services accounted for 6 percent ($966 million) of the 1996 foreign R&D investment total, with most research being funded by computer and data processing firms and companies providing research and management services. (See text table 2-21.)

U.S. Research Facilities of Foreign Firms

Consistent with the worldwide trend of multinational firms establishing an R&D presence in multiple countries, considerable growth has occurred in the number of R&D facilities operated by foreign companies in the United States. According to a 1992 survey of 255 foreign-owned freestanding R&D facilities in the United States, about half were established during the previous six years (Dalton and Serapio 1993); these data count only R&D facilities that are 50 percent or more owned by a foreign parent company.[66] An update to this study found that in 1998 there were 715 U.S. R&D facilities run by 375 foreign-owned companies from 24 different countries (Dalton and Serapio 1999). R&D facilities owned by Japanese firms continue to far outnumber those of any other coun-

[65]Totals are for R&D expenditures for U.S. affiliates of firms in which there is 10 percent or more foreign ownership. (See previous footnote.)

[66]An R&D facility typically operates under its own budget and is located in a free-standing structure outside of and separate from the parent's other U.S. facilities (e.g., sales and manufacturing). This definition of an R&D facility consequently excludes R&D departments or sections within U.S. affiliates of foreign-owned companies.

Text table 2–21.
R&D performed in the U.S. funded by affiliates of foreign companies, by selected country and industry of affiliate: 1996
(Millions of U.S. dollars)

Country	All industries	Manufacturing: Total	Drugs & medicines	Other chemicals	Machinery	Electrical equipment	Transportation equip.	Instruments	Service industries[a]	Other nonmanufacturing industries[b]
Total	17,150	13,807	5,849	1,517	935	2,954	454	720	966	2,377
Canada	1,397	1,228	1	20	D	D	11	11	21	148
Europe	12,516	11,007	5,754	1,413	532	1,581	360	520	607	902
France	1,712	1,641	474	144	97	487	42	90	32	39
Germany	3,084	2,767	1,343	478	[592]		196	56	52	265
Netherlands	948	743	1	375	1	D	D	1	8	197
Switzerland	3,375	2,985	2,575	55	[188]		–	64	366	24
United Kingdom	2,525	2,273	[1,528]		102	97	90	219	121	131
Asia and Pacific	2,592	1,159	[149]		[558]		80	45	355	1,078
Japan	2,070	1,001	72	55	204	242	77	37	337	732
Western Hemisphere	386	182	0	*	1	7	2	136	3	201
Middle East	121	106	D	D	73	D	0	8	10	5
Africa	81	70	0	5	D	D	0	0	*	11

D = withheld to avoid disclosing operations of individual companies * = less than $500,000 [ ] = indicates where categories have been combined.

NOTES: Includes foreign direct investments only of nonbank U.S. affiliates in which the affiliate has a 10-percent-or-more ownership interest. Includes R&D expenditures conducted by and for the foreign affiliates. Excludes expenditures for R&D conducted by the affiliates for others under a contract.

[a]Includes computer and data processing services ($642 million) and accounting, research and management services ($306 million).

[b]Includes wholesale trade ($1,735 million), retail trade ($32 million), petroleum ($436 million) and other industries ($174 million).

SOURCE: U.S. Bureau of Economic Analysis, *Foreign Direct Investment in the United States: Operations of U.S. Affiliates of Foreign Companies Preliminary 1996 Estimates* (Washington, DC: July 1998)

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tries: Japanese companies owned 251 R&D facilities in the United States, German companies owned 107, British companies owned 103, and French and Swiss companies each owned more than 40. (See text table 2-22.) South Korean companies have a rapidly growing presence in the United States, with 32 R&D facilities here in 1998—6 more than in 1994 and about 20 more than in 1992.

The activities of these foreign facilities were concentrated in a relatively small number of industries. In 1998 there were more than twice as many foreign-owned research sites for drugs and biotechnology (116 facilities) and chemicals and rubber (115 facilities) as for any other industry. Other industries for which there were more than 50 foreign-owned facilities in the United States included computers and computer software, high-definition television and other electronics, instruments and medical devices, and automotive products. Japanese companies account for most of the R&D centers in the electronics and automotive industries, whereas European companies have far more R&D sites focusing on pharmaceuticals and chemicals. A majority of the South Korean-owned facilities were devoted to research on computers and semiconductors.

Foreign R&D facilities were located in 39 states but were heavily concentrated in certain areas of the country. California ranks first with 188 foreign R&D facilities—notably around Silicon Valley and greater Los Angeles—but other prime locations for such sites include Detroit; Boston; Princeton, New Jersey; and North Carolina's Research Triangle Park. According to Dalton, Serapio, and Yoshida (1999), Japanese companies initially established R&D laboratories in California but recently have been moving east. Conversely, European companies began on the East Coast and are moving west.

Foreign companies have invested in U.S.-based R&D facilities for a variety of reasons. For example, growth in foreign automotive R&D centers on assisting the parent company in meeting U.S. environmental regulations and customer needs (a home-base exploiting strategy). Japanese companies in particular have expanded the scope of their R&D activities in the U.S. in line with their expansion of auto production here. Major factors behind the growth in foreign-owned biotechnology R&D facilities (much of which has resulted from the acquisition of U.S. firms) include the favorable research environment in the U.S. (especially relative to the situation in countries that are less hospitable to genetics-based R&D) and the availability of trained scientists to do the research (a home-base augmenting strategy). Much of the foundation for the U.S. competitive advantage in health care and life science research was laid by decades of substantial public R&D investments.

Text table 2–22.
Foreign-owned R&D facilities in the United States, by selected industry and country: 1998

Industry	Japan	United Kingdom	Germany	France	Switzerland	South Korea	Netherlands	Canada	Others
Total	251	103	107	44	42	32	30	32	74
Computers	24	0	2	2	0	6	2	1	5
Software	35	8	3	0	0	1	2	3	1
Semiconductors	18	0	2	0	0	10	2	0	0
Telecommunications	16	3	4	2	1	1	0	3	4
Opto-electronics	10	3	2	0	0	0	0	0	5
HDTV, other electronics	33	9	5	3	5	5	1	1	3
Drugs, biotechnology	26	15	26	7	15	2	5	0	20
Chemicals, rubber	25	18	27	14	7	1	6	7	9
Metals	8	5	2	4	1	0	0	2	4
Automotive	31	0	8	2	0	4	2	5	2
Machinery	5	6	3	4	2	0	0	3	6
Instrumentation, medical devices	6	19	7	3	6	0	3	2	7
Food, consumer goods, misc	10	12	6	1	8	1	9	5	10

NOTES: The industry-specific detail may double-count some facilities because of the multiple focus of research performed. Not all industry categories are listed. The country totals are comprehensive and do not include double-counting.

SOURCE: U.S. Department of Commerce, *Globalizing Industrial Research and Development*, by D. H. Dalton and M. G. Serapio, and P.G. Yoshida. Washington, DC, 1999.

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